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**TOPOCLIMATE AND AGRICULTURE IN TAKHINI RIVER VALLEY,
SOUTHERN YUKON TERRITORY**

by

Brenda Sproule, BSc (Hons)

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfillment of
the requirements for the degree of

Master of Arts

Department of Geography

Carleton University

Ottawa, Ontario

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submitted by Brenda Sproule, BSc (Hons)
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ABSTRACT

An assessment of agroclimatic parameters, influenced by aspect and elevation, and the representativeness of regional weather data in Takhini River Valley, southern Yukon, was undertaken between June 24 and August 20, 1995 to improve understanding of mesoclimate in this agricultural area. Air and soil temperatures, precipitation, wind speed and direction, solar radiation and soil moisture were measured at experimental stations, three on north and three on south-facing slopes, at 640, 740 and 840 m elevation. Data from permanent stations in the region were also considered. Surveys were conducted to assess relations between elevation and vegetation patterns. Mid- and high-elevation south aspect sites were warmest. Cold-air drainage resulted in the lowest minimum temperatures in the Valley bottom. The imposed 820 m elevation agroclimate limit should not apply to south aspect sites. Weather observations at Whitehorse Airport, poorly represented conditions in the Valley, except heat accumulation at mid- and high-elevation south aspect sites.

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Figure 1.1

July mean daily temperature, Yukon Territory
(Wahl et al. 1987, Fig. 8.14)

the horizontal. Convex areas or benches part way up slopes with good air drainage are warmer than concave areas. Valley bottoms are warm during the day, but, at night, cold air can be trapped in concave valley bottoms, resulting in lower minimum air temperatures (Geiger 1965; Wahl et al. 1987).

The amount of solar radiation received at a location depends on many factors, including aspect and slope of the surface. South-facing slopes receive more solar radiation than north-facing slopes, while east-facing slopes receive more solar radiation before noon than slopes facing west (Geiger 1965; Wahl et al. 1987).

In general, higher elevations receive more precipitation than valleys due to local orographic effects, and the lee side of a mountain receives less precipitation than the windward side (Geiger 1965; Reiners et al. 1984; Wahl et al. 1987).

Large-scale wind patterns result from atmospheric pressure differences. Topography deflects, funnels and channels wind flow, causing wind speed and direction to differ over short distances. In general, wind speed increases with altitude, however, the topographic influence can exceed the effect of elevation (Wahl et al. 1987).

Differential heating and cooling in valleys results in slope and valley winds. Slope winds are either anabatic

(upslope) or katabatic (downslope). Up and down valley winds develop when the valley air mass is warmer or cooler than the surrounding area and the regional pressure gradient is light (Oke 1987).

1.2 Climate of Yukon

The climate of Yukon is classified as continental sub-arctic (Wahl et al. 1987). The regime is characterized by large annual and daily ranges in temperature, low to moderate atmospheric moisture content, and moderate or light and irregular precipitation (Wahl et al. 1987).

Winters in Yukon are long and dominated by cold, dry, continental arctic air. Severe cold spells can develop, but storm tracks and the proximity to the Pacific Ocean ensure intrusions of mild air into southern Yukon during winter (Wahl et al. 1987). Rugged topography can result in large variations in temperature, regardless of whether the dominant air mass originates over the north Pacific or the Beaufort Sea. In January, mean daily temperatures recorded at weather stations range from -15°C at Whitehorse to -29°C in northern Yukon (Wahl et al. 1987). The atmosphere is usually stable over Yukon from late October to early March. During these inversions, higher elevation areas are warmer than valley-bottoms.

Spring begins by mid-April in the southernmost areas of Yukon, and has reached all of the Territory by the end of May. Long hours of sunlight during the summer promote rapid plant growth on suitable sites. July is the warmest month, and mean daily temperatures recorded at weather stations increase to 7°C on the Beaufort Sea Coast and almost 16°C at some inland locations, however, the mountainous terrain influences local air temperature (Wahl et al. 1987; Figure 1.1).

Over the Territory as a whole, local topography influences the amount of precipitation received. During the summer, the interior part of the Territory is under the influence of local convective activity and intermittent storms from the Pacific Ocean, Bering or Beaufort Seas. In winter, precipitation results from Pacific air masses that penetrate the mountains. The recorded mean annual precipitation varies from 225 to 500 mm, with more than half coming in the summer months as rain, except in the southeast portion of the Territory, where more precipitation is received as snow (Wahl et al. 1987; Smith 1992; Figure 1.2). The average soil moisture deficit ranges from 200 to 400 mm annually (Wahl et al. 1987). In southwest Yukon, where most agricultural production occurs, the St. Elias-Coast Mountains remove moisture from Pacific systems creating a

July mean daily temperature, Yukon Territory
(Wahl et al. 1987, Fig. 8.14)

Figure 1.2

Annual mean total precipitation, Yukon Territory
(Wahl et al. 1987, Fig. 9.5)

rainshadow, which limits the average annual amount of precipitation in this region to less than 250 mm (Smith 1992; Figure 1.2).

1.3 Yukon agriculture

1.3.1 Agroclimatic capability

A climatological survey was conducted in Yukon Territory and District of Mackenzie, Northwest Territories, in 1975/76 to determine the region's agroclimatic capability (Eley and Findlay 1977). Criteria used were those of the British Columbia portion of the Canada Land Inventory, modified to suit conditions north of 60 N. Adjustments were made to account for immature soils, low annual precipitation and permafrost. Similar to the Canada Land Inventory, the British Columbia portion presents a range of seven classes of climatic quality for agriculture.

Class 1 and 2 lands have no significant limitations for cultivation (Table 1.1). Class 3 lands are capable of producing small grain cereals and vegetables. Class 4 lands are restricted to forages, cold-hardy grains and vegetables. Class 5 land is suitable for forage production and cold-hardy vegetables. Class 6 lands are not suitable for cultivated agriculture, but may have some potential for native grazing. Class 7 land is not suitable for cultivated

Table 1.1

Definitions and operational constraints of land capability classes for cultivated agriculture in Yukon Territory (Tarnocai et al. 1988, Table 6)

Class 1	These lands have no significant limitations to use for the production of the full range of common Canadian agricultural crops (none in Yukon).
Class 2	These lands have slight limitations that restrict the range of some crops but still allow the production of grain and warm season vegetables (none in Yukon).
Class 3	These lands have moderate limitations that restrict the range of crops to small grain cereals and vegetables (in a few localized areas in Yukon).
Class 4	These lands have severe limitations that restrict the range of crops to forage production, marginal grain production and cold-hardy vegetables (valleys of central Yukon).
Class 5	These lands have very severe limitations that restrict the range of crops to forages, improved pastures and cold-hardy vegetables (the most common class of agricultural land in Yukon).
Class 6	These lands have such severe limitations for cultivated agriculture that cropping is not feasible. The lands may be suitable for native grazing.
Class 7	These lands have no capability for cultivated agriculture or range for domestic animals.

1.3.3 Industry profile

Presently, Yukon agriculture consists of approximately 130 agri-businesses, most of which are run as part-time operations (Smith 1992). The Territorial Government's goal is to reduce agricultural imports by 25% (Smith 1992; White et al. 1993).

The extent and distribution of cultivated land in Yukon has been controlled largely by factors such as land availability, accessibility, and proximity to communities where infrastructure, goods and services are available. Seventy-one percent of all cultivated land is located within 50 km of Whitehorse, even though this region offers only marginal growing conditions (Eley and Findlay 1977; Smith 1992). The Dawson/Mayo corridor in central Yukon, is the second largest agricultural center with respect to number of farms, area under cultivation and sales (White et al. 1993).

Typical agricultural production includes forage crops, cereals, market gardens and specialty crops such as berries. Some greenhouses produce a springtime crop of bedding plants followed by summer vegetables. Livestock operations including sheep, cattle, swine, poultry and game farming of elk, reindeer and bison for breeding stock are common (Smith 1992). There is no commercial meat production due to the absence of support services, such as a slaughter house.

Agricultural land in Yukon Territory

above sea level) and locations north of 65° are considered unsuitable for cultivation (Smith 1992; Bisset 1994). A short, variable growing season of less than 100 days, a short frost-free period, limited growing degree day (GDD) accumulations, and long, cold winters from October to May restricts growth of both annual and perennial crops. In the semi-arid environment around Whitehorse, where the majority of farming occurs, annual precipitation is less than 250 mm, further reducing agricultural potential (Wahl et al. 1987).

Soil conditions also limit agricultural production in the Territory. Yukon was glaciated during the late-Wisconsinan McConnell glaciation, except for parts of the north and west, which remained ice-free. Soils are generally weakly weathered, due to their young age, cold temperature, reduced biological activity and lack precipitation (Peake et al. 1975). In areas of low mean annual temperature, with permafrost near the ground surface, soil development can be restricted (Peake et al. 1975).

Overall, Yukon agricultural soils are deficient in available nutrients. Soil testing conducted in the Territory has indicated that 70% of soils are deficient in nitrogen, 32% in phosphate and 49% in potassium. Soils also lack magnesium. The most common micronutrient deficiency is boron (Smith 1992).

1.3.3 Industry profile

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Recent surveys place agricultural production at \$2 million annually, with another \$20-25 million invested in land, machinery and buildings (Smith 1992; White et al. 1993).

Since agriculture in southwestern Yukon is locally important from an economic perspective, and agroclimate in the area is greatly influenced by topography, an assessment of site-specific growing conditions is useful. Likewise, the agricultural value of weather data collected at the region's principal weather station, some distance from the main agricultural area, has not been evaluated.

1.4 Field work in Takhini River Valley

Between June 24 and August 20 1995, six automated weather stations were installed, three on north-facing and three on south-facing slopes, in Takhini River Valley, southern Yukon. Weather stations were located at 100 m intervals, starting at 640 m, near the Takhini River.

Experimental stations monitored air, surface and soil temperatures, solar radiation, wind speed and direction, and precipitation. Soil samples were collected to determine gravimetric moisture content, particle size, bulk density and potential-water content. Vegetation surveys were

conducted at 50 m elevation intervals, to determine the relation between elevation and vegetation patterns.

The weather data collected were used to assess agricultural limits posed by elevation and aspect, and for comparison with six permanent weather stations nearby.

1.5 Thesis objectives

In order to improve understanding of topoclimate in Takhini River Valley with respect to agricultural growing conditions, the objectives of this thesis are:

- (1) to determine if there is a significant difference in air, ground, and ground surface temperatures, solar radiation, wind speed and soil moisture with elevation and aspect in Takhini River Valley;
- (2) to determine whether a north or south-facing slope has a more favourable climate for agriculture in Takhini River Valley;
- (3) to assess the possibility of agricultural production above an elevation of 820 m;
- (4) to determine if lower elevation sites are the most favourable for agriculture production in Takhini River Valley;
- (5) to examine the influence of methods used to derive daily mean temperatures when calculating growing degree days;

- (6) to assess if weather data collected at the Whitehorse Airport is representative of weather conditions in Takhini River Valley

1.6 Scope of research and thesis organization

This thesis focuses on climatically derived limitations to agriculture in Takhini River Valley. The distribution of land for agriculture cannot be determined from agroclimatic parameters alone. Factors such as land availability and accessibility, the proximity to communities where infrastructure, goods and services are available, and the availability of water for irrigation, are also very important and need to be considered. However, these factors are beyond the scope of this research.

Due to limited time, funding and resources, the study period only encompassed part of one growing season. Short-term climate data may not represent normal conditions, or long-term trends. Because of this, conclusions may not be replicated from year to year.

This thesis is presented in five chapters. The next chapter reviews existing background information on topoclimate and agriculture. Chapter three describes the study area, and methodology used in the field and laboratory. Data analysis, results and discussion are

presented in chapter four. Chapter five summarizes and concludes the thesis.

A note on terminology

All elevations in the text are given in meters above sea level (a.s.l.).

CHAPTER 2

TOPOCLIMATE AND AGROCLIMATIC CAPABILITY OF SOUTHERN YUKON

All lands with agricultural capability are located in valleys due to the topography and climate of southern and central Yukon, and therefore are under the influence of valley mesoclimates (Eley and Findlay 1977).

The influence of topography on climate depends on elevation, aspect and inclination of the ground surface, and is more apparent during the day than at night (Geiger 1965). During the day, slopes with different orientations and inclinations receive varying amounts of solar radiation which set equalizing air currents in motion influencing air temperatures. At night, air temperatures depend on the downward flow of cooled air, therefore, differences in elevation are important, and not slope aspect or inclination (Geiger 1965).

This chapter examines previous research concerning the influence of elevation, slope and aspect on climatic variables such as incoming solar radiation, air, surface and ground temperatures, precipitation, soil moisture, wind and vegetation. In this context, the agroclimatic capability of southern Yukon will be described.

Figure 2.2

Change in air temperature with increasing elevation, during the day and at night

a) Day (after Briggs et al. 1993, Fig. 8.1)

b) Night (after Briggs et al. 1993, Fig. 8.3; Strahler and Strahler 1989, Fig. 3.8)

Figure 2.1

Geometry for direct solar beam received on a sloping surface
(after Oke 1987, Fig. A1.4)

- Z - Zenith angle
- β - Slope angle
- Ω - Solar azimuth angle
- α - Slope azimuth angle
- θ - Angle of incidence
(between Sun and the
normal to the slope)

where,

S_0 = solar constant (1353 Wm^{-2}),

r^2 = radius vector,

A = atmospheric extinction coefficient,

Z = zenith angle (degrees),

and $\cos(B)$ can be determined by (Patterson 1995, equation 12):

$$\cos(B) = \cos(\beta) \cos(Z) + \sin(\beta) \sin(Z) \cos(\Omega - \alpha) \quad (2.2)$$

where,

β = slope angle (degrees),

α = slope azimuth angle (degrees),

and Ω = solar azimuth angle (degrees)

Slopes perpendicular to the sun's rays accumulate the maximum amount of solar radiation (Geiger 1965).

As the atmosphere thins with elevation, incoming solar radiation slowly increases, as does the diurnal range between maximum and minimum radiation (Tabony 1985). However, in deep, narrow valleys, incoming solar radiation may increase rapidly with elevation, and daily total incoming solar radiation may be highest at the ridgetops due to a longer daylight period (Whiteman and Allwine 1989).

The ratio of diffuse to direct irradiance increases with decreasing solar angle (increased latitude), indicating

21
a reduction in the direct component of incoming solar radiation (Geiger 1965). At higher latitudes, the increased amount of diffuse solar radiation partially compensates for the variability of the direct component due to slope orientation (Geiger 1965; Peterson and Dirmhirn 1981; Whiteman and Allwine 1989).

2.1.2 Air temperature

In general, screen-height air temperatures decrease with increasing elevation (Geiger 1965; MacHattie and Schnelle 1974; Tabony 1985; Figure 2.2a). This negative lapse rate has been estimated to be -0.65°C per 100 m in mountainous regions by Geiger (1965), -0.55°C per 100 m by MacHattie and Schnelle (1974) and -0.6°C per 100 m by Tabony (1985). Lapse rates vary over mountainous terrain because of different topographic, climatic and vegetation characteristics at any given location.

Local topography causes differences in the lapse rates of maximum and minimum temperatures. The lapse rate of maximum temperatures is greater than that of minimum temperatures because the diurnal range of temperature is greater in a valley than on a summit due mainly to cold-air drainage into valley bottoms (Lyall 1977; Harding 1979; Tabony 1985; Harrison and Harrison 1988). MacHattie (1970)

Figure 2.2

Change in air temperature with increasing elevation, during the day and at night

a) Day (after Briggs et al. 1993, Fig. 8.1)

b) Night (after Briggs et al. 1993, Fig. 8.3; Strahler and Strahler 1989, Fig. 3.8)

found large differences in maximum temperature over an elevational gradient with increased solar radiation in the Kananaskis Valley, Alberta. The elevational effect on maximum temperatures was minor on cloudy days. The length of the growing season decreases with an increase in altitude, because of the influence of elevation on maximum air temperatures (Harrison and Harrison 1988).

Minimum air temperatures are dependent on local topography, therefore, with large topographic variations, the spatial variation of minimum temperatures will also be large (Geiger 1965). Where gradual changes in elevation occur, such as in broad valleys, the daily range in temperature is not as great as in areas where the change in altitude is more abrupt, such as in narrow valleys (Eley and Findlay 1977).

Mean daily temperatures decrease with elevation at a lesser rate than daily maximum or minimum temperatures, because higher ground tends to have a smaller range between daily maximum and minimum temperature. Because the daily range in temperature is smaller and less variable with increasing elevation from a valley bottom, frost hazard decreases with increasing elevation up to a certain altitude, even though average temperature also decreases (Eley and Findlay 1977).

2.1.3 Growing degree days (GDD)

Many meteorological factors influence plants, and temperature is one of the most important factors contributing to plant response (Edey 1977). The degree day is one method of relating heat accumulation to plant growth, development and maturity. This concept assumes that each plant has a base temperature below which it will not grow. In general, for plant growth, a base temperature of 5°C is used (Edey 1977; Eley and Findlay 1977).

The amount of heat accumulated during the day is obtained by subtracting the base temperature from the mean temperature for the day (Edey 1977; Eley and Findlay 1977; Wahl et al. 1987). This is then an index of growing conditions. Degree days may be accumulated over a period of time and related to crop development stages. However, degree day values vary in quality with respect to crop growth depending on the synoptic conditions during days on which they were accumulated, soil type, temperature, moisture, fertility and photoperiod (Eley and Findlay 1977).

The relation of growing degree days and crop growth is not linear. Several warm days together are required to achieve certain plant stages, therefore, areas with long growing seasons but uniformly low temperatures will not produce a wide range of crops in spite of large seasonal

degree day accumulations (Eley and Findlay 1977). Growing degree days are linearly related to altitude because they are derived directly from air temperature. Therefore, growing degree day accumulations decrease with increasing elevation (Pettapiece 1995).

2.1.4 Ground surface temperature

Ground surface temperature is a function of the surface energy balance. Because increased solar radiation usually results in higher ground surface temperatures, south aspect slopes have generally higher surface temperatures than north-facing slopes (Geiger 1965).

Surface temperatures change more rapidly with elevation than air temperatures. Surface temperatures are not influenced as much as air temperatures by advective effects, and are more affected by direct solar radiation (MacHattie and Schnelle 1974; Tabony 1985). Differences in surface lapse rates depend on local topography, solar radiation, ground colour and cover, and soil moisture (Geiger 1965; Tabony 1985).

2.1.5 Soil temperature

The variability of soil temperature with elevation, aspect and inclination can be related to differing soil

characteristics, depth at which soil temperature is measured, and to the microclimate at the ground surface. Green and Harding (1979) found that for seasonal mean soil temperatures, the effect of spatial variation in soil characteristics is probably less than 1°C , however, this will depend on the depth of the organic layer. This variation is small when compared with observed changes in soil temperature with altitude (Green and Harding 1979). At high elevations, lower net solar radiation decreases the energy input into the soil, and stronger airflow over wetter surfaces at high elevations results in higher evaporation rates than at drier, lower elevations, further reducing soil temperatures (Harrison 1975).

Soil temperatures experience greater rates of change with increasing elevation than air temperatures. If temperature is an expression of heat available to plants, then a more severe gradient of growth-potential exists within the soil than in the air (Harrison 1975).

Changes in solar inputs between north and south aspects influence mean soil temperatures near the ground surface (Oliver 1992). In the northern hemisphere, south-facing slopes have higher soil temperatures near the ground surface than north aspect slopes, but the warmest slopes usually face southwest because radiation before noon may be used to

evaporate any water at the ground surface, while solar radiation in the afternoon is used to heat the soil (Geiger 1965; Oliver 1992).

2.1.6 Precipitation

Precipitation over mountainous terrain varies with elevation, slope, aspect, angle of precipitation, wind speed and degree of shelter. In general, precipitation increases with elevation in mountainous regions because of orographic effects (Geiger 1965; Reiners et al. 1984; Wahl et al. 1987; Figure 2.3). Wahl et al. (1987) report an increase in precipitation of approximately eight percent for each 100 m increase in elevation in central Yukon. The rainfall/altitude gradient decreases as altitude increases (Wahl et al. 1987). Precipitation in Yukon increases with elevation to about 1500 to 2000 m and then gradually decreases (Wahl et al. 1987). Above 2000 m in elevation the lower atmospheric water content begins to limit precipitation (Wahl et al. 1987).

2.1.7 Soil moisture

Precipitation, evapotranspiration and soil properties determine the amount of soil moisture available to plants (Eley and Findlay 1977). In the northern hemisphere, south

Figure 2.3

Influence of topography on precipitation - orographic and
rainshadow effect
(after Strahler and Strahler 1989, Fig. 5.15)

aspect slopes tend to be drier than north-facing slopes due to increased amounts of solar radiation. Whiteman and Allwine (1989) report that the southwest-facing wall of Brush Creek Valley, Colorado, supports little vegetation, but, the northeast-facing slope is overlain by a dense vegetative cover.

Reiners et al. (1984) found that soil moisture content increases with altitude in the White Mountains of New Hampshire. They also found an increase in vegetation with increasing elevation, and concluded that this resulted from the increase in soil moisture observed over the elevational gradient.

2.1.8 Wind

Local topography modifies wind in two ways (Geiger 1965). First, topography deflects the wind, for example, channeling it along valleys. The nature of wind systems therefore depends on valley orientation and geometry. Second, topography modifies meteorological factors which, in turn, affect wind. In general, wind speed increases with elevation, but this elevational effect may be exceeded by topographical influences (Geiger 1965; Wahl et al. 1987).

Differential warming and cooling of valleys results in horizontal temperature and pressure gradients which cause

local wind systems to develop (Geiger 1965; Oke 1987; Sturman 1987; McKee and O'Neal 1989). These circulations are best developed in the summer under cloudless skies with weak large-scale air motion (Oke 1987).

During the day, air above the valley floor and slopes receives greater heating than air above the center of the valley. This results in an upslope (anabatic) air flow (Figure 2.4a). A closed circulation develops across the valley as the air sinks into the valley center (Oke 1987). This cross-valley circulation also transports sensible heat from the surrounding surfaces to warm the entire valley atmosphere. Therefore, when compared to the atmosphere at the same level over an adjacent plain, the valley air is warmer, creating an up-valley flow termed the valley wind (Oke 1987; Figure 2.4a). Above the valley ridges there is an anti-valley wind which flows down-valley by day (Oke 1987; Figure 2.4a). Above this anti-valley flow there is another wind associated with the large-scale synoptic pattern (Oke 1987).

At night, the emission of longwave radiation cools the valley surface. Air along valley walls cools and slides downslope under the influence of gravity (Figure 2.4b). These katabatic winds usually flow gently downhill at about 2 to 3 ms^{-1} (Oke 1987). The speed of katabatic flow depends

Figure 2.4

Mountain and valley wind system
(Oke 1987, Fig. 5.11)

a) Day

b) Night

on the thickness of the cold air layer, slope angle and surface roughness (Henderson-Sellers 1986).

A lifting motion in the valley center is created by the convergence of downslope winds which combine to form a down-valley flow known as a mountain wind (Oke 1987; Figure 2.4b). A counter flow (anti-mountain wind) flows up-valley aloft (Oke 1987; Figure 2.4b).

Topography affects the local temperature pattern most during nights when skies are clear and there is little or no wind (Eley and Findlay 1977; Oke 1987). Under these conditions, air mixing and back radiation from clouds are minimal, and the settling and pooling of cold air is intensified which may result in frosts on concave landforms, but not elsewhere (Geiger 1965; Eley and Findlay 1977). Steeper slopes, and those with convex shapes have better cold-air drainage resulting in higher minimum temperatures than shallow or concave slopes (Eley and Findlay 1977). Well-drained slopes are also subject to increased mixing of surface air with the surrounding air mass during the day. This reduces the daily maximum temperature on steep and particularly on convex slopes (Eley and Findlay 1977). As a result, well-drained slopes have a smaller daily temperature range, reduced risk of frost and a longer frost-free season than concave forms (Eley and Findlay 1977).

At night, as the coldest air settles to the lowest levels, a valley inversion results, in which air temperature increases with elevation until the ceiling of the cold air pocket is reached (Figure 2.2b). At this point, the normal adiabatic decrease of temperature with elevation prevails (Oke 1987). The area most favourable for frost sensitive crops in a valley is just above the cold air pocket, this is known as the 'thermal belt' (Oke 1987; Figure 2.5). Climatological investigations using valley (130 m) and hill (332 m) sites in central Alaska showed that valley sites are colder than hill stations at night, and warmer during the day (Wendler 1971).

2.1.9 Vegetation

Plant species tend to segregate according to their environmental requirements. Species have their own ecological distribution which is influenced by site conditions and competitive interactions (Thomas and Anderson 1993). Plant community composition at any location depends on several factors including aspect, elevation and inclination (Haase 1970; Thomas and Anderson 1993).

Different plant species may be found on north and south-facing slopes. Haase (1970) found that some plant

Figure 2.5

Development of the thermal belt
(Geiger 1965, Fig. 235)

species are found at higher elevations on south aspect slopes than on north aspect slopes.

Plant community structure changes with increasing elevation. This has been related to changes in air and soil temperatures, incoming solar radiation and soil moisture with increasing altitude (Peet 1978; Barton 1993; Thomas and Anderson 1993).

2.2 Agroclimatic capability of southern Yukon Territory

During the growing seasons of 1975 and 1976, a climatic assessment was undertaken to determine the agricultural potential of southern portions of Yukon Territory and Mackenzie District, Northwest Territories (Eley and Findlay 1977). This study involved an analysis of the main factors influencing crop growth during the growing season: heat accumulation, length of frost-free season, soil moisture and photoperiod. Temperature and precipitation data were provided by 43 long-term and 50 experimental meteorological stations. Experimental stations were arranged in 20 transects to determine effects of elevation, slope, water bodies and vegetation on local climate. This study produced forty-five 1:250,000 scale maps of agroclimatic land quality (Eley and Findlay 1977).

2.2.1 Photoperiod

The short northern growing season is partly compensated for by increased hours of sunlight during the summer months. This factor is known to accelerate the growth of most crops (Smith 1992).

Longer hours of sunlight influence air temperatures. Hourly maximum summer temperatures attain higher values because sunlight continues later in the afternoon, especially on clear, windless days (Eley and Findlay 1977). Shorter summer nights result in higher minimum air temperatures. Therefore, the accumulation of growing degree days is larger than might be expected at such high latitudes (Eley and Findlay 1977). Growing degree day normals (above 5°C; 30 year averages) based on the period from 1951 to 1980, range from 672.4 at Haines Junction to 970.4 in Mayo (Bisset 1994; Table 2.1). The Whitehorse Airport reported 881.6 growing degree days in the Normals for 1951-1980 (Table 2.1). These GDD totals are termed effective growing degree days. They are accumulated beginning 10 days after the average date when the mean daily temperature reaches 5°C, and ending on the average date of the first frost after July 15. Effective growing degree days are calculated from average mean daily air temperatures computed from monthly

Table 2.1

Climatic data for agricultural areas in Yukon - Normals - Environment Canada (1951-1980)
(Bisset 1994, Table 2.2)

	July Mean Air Temperature (°C)	May-September Total Precipitation (mm)	Growing Degree Days (GDD)	Frost Free Period (Days)	Last Frost (Spring)	First Frost (Fall)
Watson Lake	14.9	224.9	960.8	93	June 2	Sept 4
Whitehorse	14.1	145.7	881.6	82	June 8	Aug 30
Haines Junction	12.5	139.6	672.4	21	July 6	July 26
Carmacks	14.5	154.4	901.9	74	June 6	Aug 20
Fort Selkirk	14.8	161.0	926.9	61	June 16	Aug 17
Mayo	15.2	178.3	970.4	71	June 8	Aug 19
Dawson	14.7	183.3	897.8	64	June 13	Aug 17

normal values, and are adjusted using a variable multiplier, to recognize the effect of the longer daylength in the north (Pettapiece 1995).

2.2.2 Solar radiation

With the low sun angle at northern latitudes, south-facing slopes receive more solar radiation than level ground and considerably more radiation than north-facing slopes (Eley and Findlay 1977). As a result, south-facing slopes are warmer, and the difference in energy input to slopes of different orientations is marked (Taylor 1967; Eley and Findlay 1977; Oliver 1992).

2.2.3 Air temperature

The growing season in Yukon extends from May to September, and July is the warmest month. July mean temperatures in agricultural areas range from 12.5°C in Haines Junction to 15.2°C in Mayo (Bisset 1994; Table 2.1). Whitehorse has a July mean temperature of 14.1°C (Bisset 1994; Table 2.1).

Air temperatures decrease on average by 0.55°C to 0.8°C per 100 m increase in elevation over southern Yukon from April to October, whereas temperatures tend to change by

only 5°C to 10°C over hundreds of kilometers horizontally (Wahl et al. 1987). Eley and Findlay (1977) found mean daily maximum temperatures in summer to decrease by 0.75°C to 0.85°C per 100 m increase in elevation. Mean daily temperatures varied greatly with topography and proximity to water bodies. They found that maximum air temperatures recorded on south-facing slopes were approximately 0.5°C warmer than at valley-floor sites, while maximum air temperatures observed on north aspect slopes were 0.5°C cooler than valley-floor locations.

Eley and Findlay (1977) concluded that minimum air temperatures, accumulated growing degree days and length of frost-free season all decrease with elevation. They also found that steeper slopes and those with convex shapes had better cold-air drainage and higher minimum temperatures than shallow or concave slopes.

2.2.4 Ground temperature

Smith (1990) calculated a yearly average of 1015 degree days greater than 5°C at Dawson, but measured only 269 degree days greater than 5°C at 50 cm depth in the soil. In comparison, Swift Current, Alberta, had 1675 growing degree days with over 1500 growing degree days in the soil (Smith 1990). With a difference of only 660 atmospheric growing

degree days between Dawson and Swift Current, the nearly 1200 less growing degree days in the soil at Dawson reflects much colder subsoil temperatures at Yukon sites (Smith 1990).

The thermal regime of the ground is at least as important as air temperatures for agriculture. In Yukon, cryic (very cold) and pergelic (extremely cold) ground thermal regimes are recorded at 50 cm depth (Smith 1990). For example, Whitehorse soils with mean annual temperatures less than 0°C have a pergelic thermal regime (Smith 1990). In contrast, soils near Ottawa and Swift Current have mesic (mild) and frigid (cool) mean annual soil temperatures of 9°C and 6°C respectively (Smith 1990).

Soils remain frozen for more than half the year and do not begin to thaw until the end of April in most of Yukon. Surface layers are frozen by mid-October (Smith 1990).

A 5°C soil temperature is important for germination and growth of plant seeds and shoots (Smith 1990). Soil temperatures were monitored between September 1984 and July 1989 in two pedons representative of agricultural soil, one near Dawson, and the other near Whitehorse. Based on mean monthly values, temperatures in the plow layer (10 cm and 20 cm) at the Dawson site reached a maximum of 15.5°C, while at Whitehorse, the soil temperature only reached 10°C (Smith

1990, 1992). The plow layer at Whitehorse was thawed longer, but the Dawson plow layer had more degree days greater than 5°C . This indicates that, although it warms later, the soil at Dawson warms faster and cools more rapidly than the soil at Whitehorse. Thus, the effective growing season within the Dawson soil is shorter, but more intense (Smith 1990). Cooler summers contribute to the generally cooler ground thermal regime in the Whitehorse soil (Smith 1990). When irrigated and highly fertilized, soils at both these locations can produce up to 6,000 kg/ha/yr of grass for hay (Smith 1990).

2.2.5 Frost-free period

The frost-free period is determined from the date of the last killing frost (-2.0°C) measured in the air, in the spring to the first killing frost in the fall (Bisset 1994; Table 2.1). Eley and Findlay (1977) found a large variation in the length of the frost-free period between stations situated close together, but on different topographic features. They identified substantial topographic effects on climate, with minimum temperatures recorded on the valley floor 8°C to 10°C cooler than temperatures observed 150 m upslope.

The Environment Canada climatic normals for 1951-1980 reported frost-free periods ranging from 21 days in Haines Junction to 93 days at Watson Lake. In Yukon, killing frosts can occur in any month, although they are rare in July (Wahl et al. 1987; Bisset 1994; Table 2.1).

2.2.6 Precipitation

In southern Yukon, convection currents resulting from solar heating of the ground surface cause most summer precipitation which is unevenly distributed throughout the season (Eley and Findlay 1977; Wahl et al. 1987). Where the effect of daily heating is reduced, such as near large lakes, convective precipitation is also reduced (Eley and Findlay 1977).

Eley and Findlay's (1977) observations of precipitation at their temporary weather stations did not show any consistent increase or decrease with elevation. Stations in the same area with similar topography had large differences in seasonal precipitation accumulation. A comparison of values at hilltop rain gauges to those at nearby valley stations yielded precipitation gradients ranging from -11.2 mm per 100 m to 12.8 mm per 100 m. Other comparisons which did not include hilltop pairs gave values from 15 mm to 50 mm per 100 m (Eley and Findlay 1977).

Yukon weather stations report the lowest rainfall during May and highest during July (Bisset 1994). Rainfall is minimal during the planting season, and is a limiting factor for crop germination and early development. Late season rains can delay haying or decrease hay quality.

2.2.7 Soil moisture

In Yukon, precipitation events throughout the growing season are not common, therefore, crops must rely on water stored in the soil or on irrigation. Annual precipitation in agricultural areas of Yukon is only 200 mm to 400 mm, half of which is snow (Eley and Findlay 1977). Some of the water from snowmelt is unable to infiltrate frozen soil and is lost as overland flow to streams (Eley and Findlay 1977). High summer evapotranspiration rates and low precipitation, because of the rainshadow of the St. Elias Mountains, result in a soil moisture deficit of approximately 240 mm around Whitehorse (Eley and Findlay 1977).

Eley and Findlay (1977) concluded that the best climates for Yukon agriculture are found at low elevations on sunny slopes, preferably near a large river or lake. They found these locations to have the warmest temperatures and longest frost-free season. In Yukon, most valley bottoms below approximately 750 m are warm enough for some form of

agriculture (Eley and Findlay 1977). The frost-free period and accumulation of growing degree days generally allow for the production of green oats, barley, grasses and some vegetables in most areas throughout the Territory (Smith 1992).

Based partly on the findings of Eley and Findlay (1977), the Agriculture Branch of Yukon Department of Renewable Resources has set an elevational limit for agriculture at 820 m (Smith 1992; Bisset 1994).

2.3 Summary of chapter

Climatic variables such as solar radiation, air, ground surface and soil temperatures, heat accumulation, precipitation and wind are influenced by topography. The nature of these relations in mountainous regions has been the focus of many scientific investigations.

Eley and Findlay's (1977) regional agroclimatic survey did not investigate site-specific conditions within Takhini River Valley, the main agricultural region in Yukon. The applicability of Eley and Findlay's (1977) results to the Takhini River Valley and their usefulness to farmers and policy-makers is limited.

In Yukon, topography plays a large role in determining local climate. An understanding of the general relations

between topography and climate is necessary before examining site-specific topoclimatic conditions in southern Yukon.

CHAPTER 3

STUDY AREA, FIELD AND LABORATORY METHODS

This chapter describes the physical characteristics of Takhini River Valley, including physiography, soils and vegetation. Field methods used to collect weather data and soil samples are presented, as are laboratory methods used to analyze soil samples.

3.1 Physical characteristics of Takhini River Valley

3.1.1 Physiography

Takhini River Valley is located between St. Elias and Cassiar-Pelly Mountains within the Teslin Plateau. The plateau is part of the Upper Yukon Plateaus, a sub-region of the Canadian Cordillera (Day 1962; Mathews 1986; Wahl et al. 1987). The region is a rough highland cut by deep valleys, and mountain elevations range from 900 to 2000 m (Wahl et al. 1987).

Takhini River Valley is located north-west of Whitehorse, in southern Yukon Territory (see Figure 1.3). The Valley is approximately 70 km long and extends eastwards from Champagne (60°47'N 136°30'W) to the confluence of Takhini and Yukon Rivers, approximately 15 km north of

Whitehorse (Day 1962; see Figure 1.3). The Valley floor is a gently undulating lacustrine plain whose surface elevation ranges from 630 m at the river's edge near the Yukon River confluence to approximately 700 m where the Takhini River leaves Kusawa Lake (60°37'N 136°8'W; Day 1962; NTS 105 D/14 and 115 A/9).

Takhini River Valley forms part of the boundary between Teslin, Lewes, and Kluane Plateaus (Mathews 1986). The center of the valley rises to the uplands of the Kluane Plateau. At the eastern end, the walls of Takhini Valley rise smoothly to Lewes and Teslin plateaus (Day 1962).

In its upper reaches, the Takhini River's path is meandering and the flow is faster due to a narrower bed. The river winds less and the banks are lower, between the old highway crossing at Mile 938 (kilometer 1501) of the Alaska Highway and Mendenhall Landing (see Figure 1.3). In the study area, the Takhini River meanders between high silt banks eastward to its confluence with Yukon River (Day 1962).

3.1.2 Soils

Takhini Valley soils are composed mainly of lacustrine silts and clays, and are generally stone-free (Day 1962; Rostad et al. 1977; Smith 1992). Coarser-textured soils

separate the lacustrine plain from the surrounding mountains (Day 1962; Rostad et al. 1977).

Eutric Brunisol is the dominant soil within the study region, it tends to be alkaline and, sometimes, saline (Day 1962; Rostad et al. 1977; Smith 1992). Brunisolic soils develop in forests under a range of climatic environments. They have the beginnings of a soil profile, with a distinct Bm horizon indicating a changing composition, chemistry or structure (Agriculture Canada 1987). Eutric Brunisols develop on calcareous parent material and generally lack a well-developed mineral-organic surface horizon (Agriculture Canada 1987).

At lower elevations near the Takhini River, the soil parent material texture is clay loam of lacustrine origin. At higher elevations, the parent material origin is glaciofluvial, with a gravelly sandy loam texture (Agriculture Canada 1992).

3.1.3 Vegetation

Takhini River Valley is located in the central Yukon section (B26b) of the Boreal Forest vegetation region (Rowe 1972), and ecoregion 5 (Lake Laberge) of Yukon Territory (Oswald and Senyk 1977). There is tundra above treeline, which varies from 1200 m to 1350 m (Oswald and Senyk 1977).

Canadian ecoregions are being revised, and this area has been reclassified as part of the Southern Lakes Ecoregion of the Boreal Cordillera Ecozone (Energy, Mines and Resources 1993).

On terraces and plateaus, white spruce (*Picea glauca*) is dominant in more mature stands, and likely forms the climax species (Oswald and Senyk 1977). Fires have been both frequent and extensive in this region and lodgepole pine (*Pinus contorta*) occupies vast burned areas. Balsam poplar (*Populus balsamifera*) is prevalent on recent alluvium, while locations with warm aspects tend to support trembling aspen (*Populus tremuloides*), regardless of substrate. Black spruce (*Picea mariana*), alone or with white spruce, occupies wetter areas, and generally was not present in the study area. Alpine fir (*Abies lasiocarpa*) is found in the subalpine below treeline, paper birch (*Betula papyrifera*) is scattered, commonly on cooler aspects (Oswald and Senyk 1977). Other tree species found include green alder (*Alnus crispa*) and several species of willow (*Salix* spp.).

Common shrubs include soapberry (*Shepherdia canadensis*), willows (*Salix* spp.), labrador tea (*Ledum palustre*) and prickly rose (*Rosa acicularis*). Flowers characteristic of the region are fireweed (*Epilobium angustifolium*), goldenrod (*Solidago decumbens*), arctic

lupine (*Lupinus articus*), death camas (*Zygadenus elegans*) and northern yarrow (*Achillea borealis*). Ground cover consists of kinnikinnik (*Arctostaphylos uva-ursi*), twinflower (*Linnaea borealis*) and low-bush cranberry (*Vaccinium vitis-idaea*).

3.2 Field methods

During summer 1995, from June 24 to August 20, six experimental weather stations were installed across the Takhini River Valley near Whitehorse, to monitor growing conditions over the season at various elevations (Figure 3.1). The weather data collected were used to assess agricultural limits posed by elevation and aspect, and for comparison with six permanent area weather stations (Figure 3.1).

3.2.1 Site selection

The area was surveyed in June from accessible roads and potential sites were investigated on foot. Permission for land access was acquired from owners when sites selected were located on private property.

Experimental weather stations were located in accessible, open areas, representing agricultural growing conditions. Easy access to the sites was important, because

Figure 3.3

Location of vegetation sampling sites in Takhini River Valley, southern Yukon Territory

dataloggers used had limited storage capacity, and data had to be retrieved frequently.

Six experimental weather stations were installed, three on north-facing slopes and three on south-facing slopes. Aspect, measured in absolute degrees, was 0° or 180° , $\pm 15^\circ$. The ideal slope for the cultivation of most crops is between 0.5° and 3° , a slight slope is important for drainage (Symons 1978). Difficulties with machinery are encountered on slopes inclined more than 7° (Symons 1978). For this research, slope was less than 15° , which represents the limit for mechanized agricultural production (Symons 1978).

Sites were located at intervals of 100 m in elevation, beginning near the Takhini River at 640 m and ending at 840 m, above the accepted 820 m limit for agricultural production in Yukon (Smith 1992; Bisset 1994; Figure 3.1). For cereal production, low-elevation, south aspect sites near the river, are favoured (Bisset 1990). Experimental sites above 820 m were necessary to examine the feasibility of agriculture above this elevation.

3.2.2 Instrumentation and method of data collection

3.2.2.1 Variables monitored

Variables monitored were air, ground surface and ground temperatures, incoming solar radiation, wind speed and

direction, and precipitation. Soil samples were collected for moisture content, bulk density, particle size and potential-water content analysis. Vegetation surveys were undertaken to determine relations between elevation and vegetation patterns.

3.2.2.2 Climatic variables

Air and ground temperatures were measured by Campbell Scientific CR-10 dataloggers, using thermistors with 10 000 ohm bridge resistors ($\pm 0.03^{\circ}\text{C}$). Ground surface temperatures were monitored using thermistors with 1000 ohm bridge resistors ($\pm 0.1^{\circ}\text{C}$).

Thermistors measuring air and ground surface temperatures were placed in radiation shields. These shields consisted of five stacked, evenly spaced white plastic plates with a hole drilled in the center of the three middle plates for the thermistor. The air temperature shield was screwed onto the top of 3/4 inch diameter steel pipe, 1.5 m above the ground (Figure 3.2). The ground surface shield was fixed to a wooden dowel, so that the sensor was 5 cm above the ground (Figure 3.2). Ground thermistors were taped to a wooden dowel placed in the ground to a depth of approximately 15 cm, equivalent to the plow depth (Bisset 1994; Figure 3.2).

Figure 3.2

Equipment installed at experimental weather stations in
Takhini River Valley, southern Yukon Territory

Incoming direct and diffuse solar radiation were monitored using two Kipp pyranometers. At the beginning of the monitoring period, pyranometers were attached to a 3/4 inch diameter steel pipe approximately 0.5 m above the ground, and leveled (Figure 3.2). On July 20, they were tilted parallel to the slope, to better measure the solar radiation reaching the sloping ground surface. Pyranometers were located at the mid-elevation sites.

Wind speed was measured with R.M. Young Wind Sentry anemometers ($\pm 2\%$). Anemometers were mounted similarly to air temperature shields (Figure 3.2). On July 20, the anemometer at Site 6 was elevated to 4.3 m above the ground surface to avoid the influence of surrounding trees, which would be absent in an agricultural setting.

R.M. Young Wind Sentry vanes ($\pm 5^\circ$), were used to measure wind direction at the two mid-elevation sites. At these locations, the wind vane and anemometer were mounted on a north-south oriented cross-arm, with the wind vane at the north end (Figure 3.2). The cross-arm was in turn mounted on a 3/4 inch diameter pipe, 1.5 m above the ground surface. Wind vanes were oriented so that a wind from the south registered as 180° .

Data from the thermistors and instruments were recorded on Campbell CR-10 dataloggers which stored measurements

every tenth minute. Data were retrieved from the low- and mid-elevation sites every 2 days, and from the high-elevation sites at least weekly to avoid overlapping values. CR-10s installed at low- and mid-elevation sites had only 5,332 two byte memory locations each, whereas the two loggers at 840 m had 29,908 two byte memory locations each.

3.2.2.3 Precipitation

Rain gauges were made from tin cans topped with funnels which were taped flush to the rim of the cans, leaving only a small opening, to minimize evaporation from the reservoir. They were placed at each site with the gauge opening approximately 5 cm above the ground surface, parallel to the slope (Figure 3.2). The amount of precipitation in each can was measured weekly using a graduated cylinder (± 0.5 mL).

3.2.2.4 Soil moisture

To create comparable soil moisture study sites, the organic layer was removed from a 2 m by 2 m plot near each weather station (Figure 3.2). The soil was turned over by hand, similar to working an agricultural field, and all soil moisture samples were taken from these standardized plots.

Each week, a soil auger was used to take eight random soil samples within each plot. Four samples were taken from

0-15 cm, and four from 15-30 cm. This tool produced a 2.5 cm diameter core which was placed in an airtight bag. Samples from the lower level were not collected from Sites 4 and 5 due to compacted soil which could not be penetrated with the auger. Holes left by the auger were loosely filled with soil after each sampling.

3.2.2.5 Vegetation surveys

Vegetation surveys were conducted at 50 m elevation intervals, between 640 m and 890 m inclusive (Figure 3.3). Sites sampled during the surveys met the same criteria with regard to slope and aspect as the experimental weather stations. For consistency, all vegetation sampling sites were located in areas burned by the 1958 fire in Takhini River Valley. At each location, two or three 10 m by 10 m plots were staked, and the number of trees, shrubs and saplings were counted to determine tree density (individuals/100 m²) in each plot. A 1 m by 1 m grid divided into 20 cm by 20 cm squares was used at five randomly chosen locations within each 100 m² plot to determine presence or absence of herbaceous plant species.

Plants were identified in the field when possible, or samples were taken and dried for later identification using

Figure 3.3

Location of vegetation sampling sites in Takhini River Valley, southern Yukon Territory

various reference texts (Porsild and Cody 1980; Trelawny 1988; Pratt 1991).

3.2.2.6 Soil potential-water content, bulk density and particle size

Mineral soil samples for potential-water content, bulk density and particle size analysis were collected with organic layer removed, from one random location at each site, including all the vegetation sites. The sampling tool consisted of a 7.6 cm diameter, 10 cm long pipe serrated at one end and attached to a T-shaped handle. This auger bore into the soil with a twisting motion of the handle, creating a soil sample of known volume with minimal compaction. Samples were placed in air-tight bags.

3.2.2.7 Topography

Slope angle and aspect were determined for instrumented sites and vegetation sites using a clinometer-Brunton compass.

Elevation was determined using a digital altimeter, which was calibrated each morning before taking readings, using a known benchmark. Weekly readings at instrumented sites were averaged over the entire study period, while readings were taken only once at the vegetation sites.

3.3 Laboratory methods

Laboratory work was completed in Whitehorse, at the Transportation Engineering Laboratory, Yukon Department of Community and Transportation Services, at the Central Experimental Farm of Agriculture Canada in Ottawa, and at Carleton University.

3.3.1 Soil moisture, potential-water content and soil bulk density

Soil samples were dried in soil ovens at the Transportation Engineering Building, 201 Range Road, Whitehorse. The gravimetric water content (%) was calculated for each sample by dividing the mass of water by the mass of dry soil.

The potential-water content relation was determined for one upper (0-15 cm) and one lower (15-30 cm) soil sample from each experimental weather station. Water retention was determined by pressure plate extraction at field capacity (-0.3 bar) and at the wilting point (-15 bar) for the disturbed samples (Topp et al. 1993).

Bulk density (g/cm^3) was estimated for each sample from the measured dry weight of the soil sample divided by the known volume of the soil plug.

3.3.2 Soil particle size analysis

Soil texture was determined by the pipette method (Torrance and Patterson 1993). Soil aggregates were dispersed by chemical, mechanical and ultrasonic means, and particles were separated according to size limits by sieve for the sand-size material, and by sedimentation, using the pipette method, for various fractions of fine-grained sediment. Soils were classified according to the Soil Texture Triangle (United States Department of Agriculture 1951).

3.4 Site descriptions

Site descriptions were obtained through observation, land-owner interview and the quantitative methods previously described in this chapter.

Site 1

Site 1 (60°52'N 135°31'W; low-elevation, north-facing) was located approximately 100 m from the edge of Takhini River. The site was at an elevation of 640 m (2099 ft), near the middle of an 8.3° pitch facing 0° (Table 3.1).

The land was cleared by heavy equipment in April 1995. However, a willow-aspen forest remains above the site. The slope is sparsely vegetated with kinnikinnik, willow, Eskimo

Table 3.1

Experimental weather station site characteristics in
Takhini River Valley, southern Yukon Territory

SITE*	LAT/LONG	ASPECT	ELEVATION	SLOPE
1 (l.n.)	60°52'N 135°31'W	0°	640 m	8.3°
2 (m.n.)	60°49'N 135°18'W	14°	740 m	14.5°
3 (h.n.)	60°48'N 135°25'W	0°	840 m	15°
4 (l.s.)	60°51'N 135°21'W	190°	640 m	6°
5 (m.s.)	60°54'N 135°13'W	184°	740 m	4.5°
6 (h.s.)	60°54'N 135°14'W	190°	840 m	6.8°

*see Figure 3.1 for site locations

l=low-elevation

m=mid-elevation

h=high-elevation

n=north aspect

s=south aspect

Potato (*Hedysarum* spp.) and aspen saplings. The surface soil (0-15 cm) is a silt loam, and the subsoil (15-30 cm) is a silt (Table 3.2). The bulk density of the surface soil is 0.9 g/cm^3 and the subsoil is 1.2 g/cm^3 (Table 3.2). At field capacity (-0.3 bar), the moisture contents for the upper and lower soil samples are 36.4% and 24.8% respectively (Table 3.2). The water content at the wilting point (-15 bar) is 13.2% for the upper soil sample, and 7.5% for the lower sample (Table 3.2).

Site 2

Site 2 ($60^{\circ}49'N$ $135^{\circ}18'W$; mid-elevation, north-facing) was installed at an elevation of 740 m (2427 ft), near the middle of an approximately 30 m long, 14.5° slope (Table 3.1). A terrace above the slope was previously seeded with grass and a terrace below supported spruce, aspen and willow. The slope aspect at this site is 14° (Table 3.1).

This land was cleared, but never broken and maintained a sparse vegetation cover consisting of spruce saplings, willows, kinnikinnik, labrador tea and fireweed. Both upper and lower soils are silt loams (Table 3.2). The bulk density of the surface soil is 1.3 g/cm^3 and subsoil is 1.3 g/cm^3 (Table 3.2). At field capacity, the moisture contents for the upper and lower soil samples are 17.1% and 13.9%.

Figure 3.4

Relation between incoming solar radiation measured by experimental (A and B) and standard pyranometers (Agriculture Canada)

a) North aspect pyranometer (A)

b) South aspect pyranometer (B)

respectively (Table 3.2). The water content at the wilting point is 4.4% for the upper soil sample, and 5.7% for the lower sample (Table 3.2).

Site 3

Site 3 (60°48'N 135°25'W; high-elevation, north-facing) was situated in a fuelwood cutting area off Scout Lake Road at an elevation of 840 m (2755 ft). The equipment was positioned near the middle of a 15° slope facing 0° (Table 3.1).

Sparse pine and spruce trees, labrador tea, lowbush cranberry and prickly rose grow at this site. Both upper and lower soils are sandy loams (Table 3.2). The bulk density of the surface soil is 1.2 g/cm³, and 1.5 g/cm³ for the subsoil (Table 3.2). The moisture contents at field capacity for the upper and lower soil samples are 14.1% and 8.4% respectively (Table 3.2). At the wilting point, the water content is 3.5% for the upper soil sample, and 3.4% for the lower sample (Table 3.2).

Site 4

Site 4 (60°51'N 135°21'W; low-elevation, south-facing) was located south of Takhini Hotsprings Road on a gradual undulating slope approximately 150 m from the Takhini River

edge at an elevation of 640 m (2099 ft). The slope faces 190° with a pitch of 6° (Table 3.1).

This land was first cleared in winter 1983, broken in summer 1984, and disked twice. For three years it was seeded with oats. An irrigated vegetable garden was cultivated approximately 50 m away, but the site has been fallow for the last 3 years. Currently, it maintains a sparse cover of brome grass (*Bromus inermis* var *carleton*). The surface soil is a silt loam, and the subsoil is a loam (Table 3.2). The surface soil bulk density is 1.4 g/cm³, and the subsoil bulk density is 1.5 g/cm³ (Table 3.2). The moisture contents at field capacity for the upper and lower soil samples are 17.1% and 14.0% respectively (Table 3.2). At the wilting point, the water content is 5.4% for the upper soil sample, and 5.1% for the lower sample (Table 3.2).

Site 5

Site 5 (60°54'N 135°13'W; mid-level, south-facing) was located at an elevation of 740 m (2427 ft), on a wide, 4.5° slope, with an orientation of 184° (Table 3.1). This land was first cleared, broken and disked in 1986. Since then it has supported oats and alfalfa, but has not been worked since 1990, when it was seeded with brome grass.

Both upper (0-15 cm) and lower (15-30 cm) soils are silt loams (Table 3.2). The upper level soil bulk density is 1.3 g/cm^3 , and lower level is 1.6 g/cm^3 (Table 3.2). At field capacity, the water content is 15.2% for the upper soil sample and 10.5% for the lower soil sample (Table 3.2). The moisture contents at the wilting point for the upper and lower soil samples are 3.8% and 3.5% respectively (Table 3.2).

Site 6

Site 6 ($60^{\circ}54'N$ $135^{\circ}14'W$; high-elevation, south-facing) was located at an elevation of 840 m (2755 ft) near the top of a 6.8° slope with an aspect of 190° (Table 3.1). In order to create conditions more similar to an open agricultural setting the area was manually cleared of forest growth.

The vegetation at this site consisted mainly of aspen, willow and soapberry bushes. Both upper and lower soils are silt loams (Table 3.2). The surface soil bulk density is 1.2 g/cm^3 , and subsoil is 1.2 g/cm^3 (Table 3.2). At field capacity, the moisture contents for the upper and lower soil samples are 17.4% and 12.1% respectively (Table 3.2). The water content at the wilting point is 4.1% for the upper soil sample, and 4.2% for the lower sample (Table 3.2).

Permanent weather stations

Whitehorse Airport ($60^{\circ}42'N$ $135^{\circ}04'W$) is located at an elevation of 703 m on a bench adjacent to the steep western escarpment of Yukon River (Wahl et al. 1987; Figure 3.1). Downtown Whitehorse lies on the valley floor, approximately 60 m below and 400 m east of the airport (Environment Canada 1984; Figure 3.1).

Other permanent weather stations providing data include the Forestry Nursery ($60^{\circ}51'N$ $135^{\circ}12'W$) located at an elevation of 670 m at the southwest corner of the Klondike Highway and Takhini River Road, Takhini River Ranch ($60^{\circ}52'N$ $135^{\circ}32'W$) at an elevation of 756 m, Porter Creek ($60^{\circ}46'N$ $135^{\circ}07'W$) at an elevation of 713 m, Hackney Sheep Farm ($60^{\circ}52'N$ $135^{\circ}23'W$) at an elevation of 686 m, and Mayo Road station ($60^{\circ}52'N$ $135^{\circ}11'W$) which is located at an elevation of 655 m at Mile 5.5 Mayo Road (Figure 3.1).

3.5 Equipment calibration

3.5.1 Thermistors

Thermistors were calibrated to $0.001^{\circ}C$, by the Geological Survey of Canada. The Steinhart-Hart equation, an expression of the resistance-temperature relation for thermistors, was used to determine actual temperatures from resistance values stored on dataloggers and calibration

constants determined for each thermistor (YSI 1996). Temperatures recorded in the field were corrected with respect to calibrated temperatures if the differences were greater than 0.05°C .

3.5.2 Pyranometers

Pyranometers used in the field were calibrated with respect to a standard pyranometer ($\pm 5\%$) provided by Agriculture Canada. All three pyranometers were run side by side for five days on an open grass surface. Regression analysis was used to determine the relation between the standard and the experimental pyranometer (Figure 3.4). Experimental values from the north aspect pyranometers were corrected by $+14.4 \text{ Wm}^{-2}$, and the south aspect pyranometer was corrected by $+20.5 \text{ Wm}^{-2}$.

3.6 Statistical procedures

Summary statistics (mean, maximum, minimum, average difference, standard error, standard deviation and correlation analysis), were applied to analyze site details and comparisons using Excel 5.0 (Microsoft Inc. 1993).

A Mann-Whitney U Test, using SPSS 6.1.2. (SPSS Inc. 1995), was used to determine significant difference at the

Figure 3.4

Relation between incoming solar radiation measured by
experimental (A and B) and standard pyranometers
(Agriculture Canada)

a) North aspect pyranometer (A)

b) South aspect pyranometer (B)

95% confidence level between variables monitored at experimental and permanent weather stations.

3.7 Summary of chapter

The Takhini River Valley study area was situated in the Upper Yukon Plateaus. The Valley extends eastward for approximately 70 km from Champagne to the river's confluence with the Yukon River. Soils in the area are poorly developed and support a boreal forest.

The study period extended from June 24 to August 20 1995, during which time six experimental weather stations monitored air, ground surface and soil temperatures, solar radiation, wind speed and direction, and precipitation in Takhini River Valley. Soil samples were collected and analyzed using established methods, and vegetation surveys conducted.

Research sites were selected to represent agricultural growing conditions on various aspects, and to be easily accessible (Table 3.1). Instruments were selected based on portability and to require minimum maintenance. As a result of these requirements the equipment differed from the permanent standard weather stations.

When discussing and interpreting weather data gathered during the study period, and comparing experimental data to

those from permanent stations, physical characteristics of the study area and field methods must be considered.

CHAPTER 4

DATA ANALYSIS, RESULTS AND DISCUSSION

Weather data collected at experimental weather stations were used to assess agricultural limitations posed by elevation and aspect, and were compared with six permanent weather stations nearby. Experimental weather stations in Takhini River Valley recorded air, ground surface, and soil temperatures, incoming solar radiation, wind speed and direction. Soil samples were collected for moisture content, particle size, bulk density and potential-water content analysis. Vegetation surveys were undertaken to determine relations between elevation and vegetation patterns.

Data were collected in order to assess the agroclimatic capability of north and south aspect slopes; to determine the validity of the 820 m elevation limit for cultivated agriculture; for an assessment of agroclimate at low elevation sites; to assess the growing degree day concept, and to determine how representative the agroclimatic data collected at the Whitehorse Airport is of agroclimate in the region.

4.1 Analytical methods

4.1.1 Air, ground surface and soil temperatures, wind speed and solar radiation

Daily average air, ground surface and soil temperatures and wind speeds at experimental weather stations, were calculated as the mean of the 10 minute observations in 24 hour periods from 0000 local time. Daily maximum and minimum temperatures and wind speeds were recorded from the highest and lowest observations on each day.

The Whitehorse Airport and Forestry weather stations record air temperatures hourly. The Airport Station also records daily maximum and minimum air temperatures. All other permanent weather stations in Takhini River Valley only record daily maximum and minimum air temperatures. Daily average air temperatures are calculated as the mean of the maximum and minimum temperatures at the permanent stations. For the Forestry station, daily average air temperatures were calculated as the mean of the hourly maximum and minimum temperature observations.

Two trends are evident in the air temperature data (Figure 4.1). From June 24 to July 23, day to day variability in air temperature was greater than from July 24 to August 20. Air temperature observations at all stations were divided into two groups to compare these patterns.

Figure 4.1

Example of daily average air temperature pattern observed at experimental and permanent weather stations in Takhini River Valley, southern Yukon Territory

For each station, the average air temperature and standard deviation were calculated for both time periods.

To determine the strength, direction and significance of the linear relation of daily average and minimum air temperatures recorded at weather stations, the Spearman rank correlation coefficient (r_s) for non-normally distributed data was used.

Daily average, maximum and minimum air, ground surface, soil temperatures and wind speeds were plotted versus time, in days, for the study period. When air temperature observations from permanent stations were plotted with temperatures from experimental stations, the daily average for the latter was the mean of the daily maximum and minimum air temperatures recorded at those stations. Due to occasional malfunctioning of thermistors and dataloggers, some data sets are incomplete.

Total incoming solar radiation was calculated for the mid-elevation experimental weather stations by summing hourly observations. Total daily incoming solar radiation was calculated by multiplying the sum of the hourly observations by 3600 seconds. This method assumes that the incoming radiation value remains constant for the entire hour. These values were plotted versus time, in days, for June 27 to August 9, 1995.

Average differences in temperatures, wind speed and solar radiation between sites were determined, and sites were compared using the non-parametric Mann-Whitney U test at a confidence level of 95% for 2-tailed tests (Ebdon 1985). This analysis was done on a microcomputer.

4.1.2 Growing degree days

Growing degree day (GDD) accumulations, using air temperatures, were calculated for each experimental and permanent weather station. Growing degree day accumulations were also determined for each experimental station at 15 cm in the soil. Growing degree days were calculated by subtracting a base temperature of 5°C from the daily mean temperature. For this purpose, daily mean temperatures were calculated by averaging the maximum and minimum temperatures for the day.

Example:

Maximum temperature (°C):28

Minimum temperature (°C):10

Mean temperature (°C) = $\frac{\text{Max.} + \text{Min.}}{2} = 19$

Growing degree days at base 5°C = $19 - 5 = 14$ °C

2

OF/DE

2

PM-1 3 1/2" x 4" PHOTOGRAPHIC MICROCOPY TARGET
NBS 1010a ANSI/ISO #2 EQUIVALENT

PRECISIONSM RESOLUTION TARGETS

Growing degree days were accumulated over the 50-day period for which a complete data set was available.

At the experimental weather stations, degree days in the air were calculated a second time by subtracting a base temperature of 5°C from the daily mean temperature observations. In this case, the daily temperature was the mean of the 10-minute observations in 24-hour period from 0000 local time. Growing degree days were accumulated over the same 50-day period for which a complete data set was available.

4.1.3 Wind direction

The Takhini River Valley generally runs east-west, therefore, upslope and downslope winds are either north or south in direction. Each 10 minute observation of wind direction was classified into one of 10 groups (Table 4.1). Class 1 was a southerly wind (170°-189°), and Class 10, a northerly wind (350°-9°). Wind direction classes and incoming solar radiation were plotted versus time at the two mid-elevation sites for sample sunny and cloudy days.

4.1.4 Precipitation

The amount of precipitation in millimeters was determined for each site by converting the volume of water

Table 4.1

Wind direction classes

WIND DIRECTION (Degrees)	WIND DIRECTION CLASS
350-09	10
330-349;10-29	9
310-329;30-49	8
290-309;50-69	7
270-289;70-89	6
250-269;90-109	5
230-249;110-129	4
210-229;130-149	3
190-209;150-169	2
170-189	1

80

trapped in the rain gauge as measured with a graduated cylinder from milliliters to mm³ and dividing by the surface area of the rain gauge. The amount of precipitation in millimeters was then plotted versus time in days.

4.1.5 Vegetation

The presence of vegetation species was charted over the elevational gradient on both north and south aspect slopes, and species present at all six sampling elevations (omnipresent) were excluded. To aid in assessing climatic conditions above the 820 m elevation limit, the number of plant species present at 790 m and the number of species which reappear at 840 m were determined for both north and south-facing slopes. It was assumed that the slope which had the greater number of reappearing species from 790 m to 840 m shared more similar climatic conditions at these two elevations. Slope aspect and inclination, and soil characteristics were relatively uniform at all vegetation survey sites (Tables 4.2 and 4.3).

4.1.6 Soil moisture and potential-water content, bulk density and particle size

Average gravimetric water content (%) was determined for the four upper level (0-15 cm) and four lower level

Table 4.2

Vegetation sampling site characteristics in
Takhini River Valley, southern Yukon Territory

SITE*	LAT/LONG	ASPECT	ELEVATION	SLOPE
A	60°51'N 135°31'W	6°	640 m	6.4°
B	60°50'N 135°19'W	10°	690 m	10°
C	60°49'N 135°18'W	5°	740 m	7.3°
D	60°48'N 135°22'W	11°	790 m	5.5°
E	60°48'N 135°23'W	8°	840 m	8°
F	60°48'N 135°25'W	355°	890 m	9.2°
G	60°52'N 135°25'W	190°	640 m	8.2°
H	60°51'N 135°20'W	175°	690 m	7.8°
I	60°53'N 135°13'W	176°	740 m	6.2°
J	60°54'N 135°13'W	185°	790 m	8.4°
K	60°54'N 135°14'W	181°	840 m	5.6°
L	60°54'N 135°14'W	179°	890 m	11.4°

* see Figure 3.3 for site locations

Table 4.3

Soil texture and bulk density at vegetation sampling sites in Takhini River Valley,
southern Yukon Territory

LOCATION*	SOIL DEPTH (cm)	% SAND	% SILT	% CLAY	TEXTURE CLASS	BULK DENSITY g/cm ³
A (N640 m)	0-15	8	79	13	silt loam	1.0
B (N690 m)	0-15	14	68	18	silt loam	1.1
C (N740 m)	0-15	32	59	9	silt loam	1.1
D (N790 m)	0-15	34	62	4	silt loam	0.8
E (N840 m)	0-15	52	39	9	loam	1.4
F (N890 m)	0-15	78	21	3	sandy loam	1.3
G (S640 m)	0-15	37	62	1	silt loam	1.4
H (S690 m)	0-15	29	65	6	silt loam	1.3
I (S740 m)	0-15	48	51	1	silt loam	1.3
J (S790 m)	0-15	42	54	4	silt loam	1.3
K (S840 m)	0-15	44	55	1	silt loam	1.2
L (S890 m)	0-15	34	65	1	silt loam	1.2

*see Figure 3.3 for site locations

(15-30 cm) soil samples collected each week at the experimental weather station by the method previously described in section 3.3.1. To place gravimetric water content results in context, the potential-water content relation was determined for one upper and one lower soil sample from each experimental weather station by the method also previously described in section 3.3.1.

Bulk density and particle size were determined for one upper (0-15 cm) and one lower (15-30 cm) soil sample collected at experimental weather stations and vegetation sampling sites, using methods described in sections 3.3.1 and 3.3.2. Lower level soil samples could not be obtained from the 790 m and 890 m vegetation sites on the north aspect slope due to gravel content in the soil.

4.2 Results and discussion

4.2.1 Agroclimate of north and south slopes in Takhini River Valley

In temperate and sub-arctic regions of the northern hemisphere, south aspect sites are more favourable for cultivated agriculture than north-facing sites, because they are warmer (Geiger 1965; Henderson-Sellers 1986; Oke 1987). In Takhini River Valley, this is illustrated by a comparison of agroclimatic factors at pairs of experimental weather

stations on north and south aspect slopes. South-facing slopes received significantly more total daily incoming solar radiation (Figure 4.2; Table 4.4). In general, slopes which receive more solar radiation are warmer (Gorke 1965; Henderson-Sellers 1986; Oke 1987). This is reflected in higher air, ground surface and soil temperatures at south aspect sites.

Weather stations on the south-facing slope, recorded higher daily average, maximum and minimum air temperatures than the corresponding north aspect sites, except Site 2 on the north aspect slope which recorded higher daily maximum air temperatures than Site 5 on the south aspect slope (Table 4.5). Faster winds at Site 5 than at Site 2, reduced maximum air temperatures at the former through advection (Figure 4.3). Site 5 was located in an open field, whereas Site 2 was more sheltered by vegetation. The north aspect, low-elevation site recorded lower minimum air temperatures and more frosts than the corresponding south aspect site (Figure 4.4; Table 4.6). The mid-elevation sites did not record any air temperatures below 0°C (Table 4.6). The high-elevation north aspect site recorded two frosts, whereas the corresponding south aspect site did not record any frosts (Table 4.6).

Figure 4.2

Daily total incoming solar radiation at mid-elevation (740 m) experimental weather stations in Takhini River Valley, southern Yukon Territory (June 27-August 9, 1995)

Table 4.4

Average difference in total daily incoming solar radiation accumulated between June 27 and August 9 1995, at mid-elevation (740 m) experimental weather stations in Takhini River Valley, southern Yukon Territory

SITES		AVERAGE DIFFERENCE (south-north)	STANDARD ERROR OF THE DIFFERENCE
South	North	3.003 MJm^{-2} *	1.085 MJm^{-2}

*difference is statistically significant ($p < 0.05$)

Table 4.5

Average difference in air, ground surface and soil temperatures between corresponding low-, mid- and high-elevation experimental weather stations on north and south aspect slopes in Takhini River Valley, southern Yukon (June 24-August 20, 1965)

AIR TEMPERATURE (°C)									
SITES		AVERAGE			MAXIMUM			MINIMUM	
A	B	AVG DIFF	ERROR		AVG DIFF	ERROR		AVG DIFF	ERROR
4 (l.s.)	1 (l.n.)	0.4	0.5		0.4	0.6		1.0	0.8
5 (m.s.)	2 (m.n.)	0.1	0.5		-1.0	0.7		1.4	0.6
6 (h.s.)	3 (h.n.)	0.3	0.5		0.4	0.6		1.4	0.6
SURFACE TEMPERATURE (°C)									
SITES		AVERAGE			MAXIMUM			MINIMUM	
A	B	AVG DIFF	ERROR		AVG DIFF	ERROR		AVG DIFF	ERROR
4 (l.s.)	1 (l.n.)	1.1	0.5		4.1	1.1		1.0	0.8
5 (m.s.)	2 (m.n.)	0.8	0.5		1.7	0.8		0.7	0.8
6 (h.s.)	3 (h.n.)	0.8	0.5		3.2	1.1		1.1	0.7
SOIL TEMPERATURE (°C)									
SITES		AVERAGE			MAXIMUM			MINIMUM	
A	B	AVG DIFF	ERROR		AVG DIFF	ERROR		AVG DIFF	ERROR
4 (l.s.)	1 (l.n.)	4.2	0.3		5.6	0.3		4.2	0.3
5 (m.s.)	2 (m.n.)	2.3	0.3		3.3	0.4		1.4	0.3
6 (h.s.)	3 (h.n.)	3.8	0.2		4.5	0.3		3.0	0.3

l=low elevation (640 m)

m=mid elevation (740 m)

h=high elevation (840 m)

s=south aspect; n=north aspect

AvG Diff=average difference (A-B)

Error=standard error of the difference

bold type=difference is statistically significant ($p < 0.05$)

Figure 4.3

Daily average wind speed recorded at north and south aspect
mid-elevation (740 m) experimental weather stations in
Takhina River Valley, southern Yukon Territory
(June 24-August 20, 1996)

Figure 4.4

Daily minimum air temperature recorded at north and south aspect low-elevation (640 m) experimental weather stations in Takhini River Valley, southern Yukon Territory (June 25-August 20, 1995)

Table 4.6

Number of frosts ($<0^{\circ}\text{C}$) and killing frosts ($\leq -2^{\circ}\text{C}$) at 1.5 m (air) and 5 cm (surface) above the ground surface, at experimental and permanent weather stations, southern Yukon Territory (July 1-August 30, 1991).

SITES	ELEVATION	AIR FROSTS ($<0^{\circ}\text{C}$)	AIR FROSTS ($\leq -2^{\circ}\text{C}$)	SURFACE FROSTS ($<0^{\circ}\text{C}$)	SURFACE FROSTS ($\leq -2^{\circ}\text{C}$)
1 (north)	640 m	7	0	14	10
2 (north)	740 m	0	0	5*	0*
3 (north)	840 m	2*	0*	10*	2*
4 (south)	640 m	4	0	11	4
5 (south)	740 m	0	0	4	0
6 (south)	840 m	0	0	5	0
Go Road	655 m	1	0		
Forestry	670 m	5	1		
Hackney Farm	686 m	0	0		
Whitehorse A.	703 m	0	0		
Porter Creek	713 m	0	0		
Takhini Ranch	756 m	1	0		

*=missing temperature observations due to malfunctioning of equipment

~=data not available

germination south aspect slopes were more favourable than those facing north.

In Takhini River Valley, greater exposure to solar radiation on the south aspect slope allowed for more heat to accumulate in the plow layer than on the north aspect (Figure 4.8). However, the study period did not include the early growing season (May and beginning June) when soil temperatures are critical to seed germination and early plant development. Seeding time depends on the minimum soil temperature required for germination, which varies depending on crop type. For example, the minimum soil temperature for some forages, such as alfalfa, is 1°C, whereas, for pumpkins it is 16°C (Bisset 1994). Smith (1990) found that soil temperatures at a depth of 10 cm on level ground in the Whitehorse area remain below 5°C from the end of September to late May. Most seeding is complete by the end of May. Therefore, the elevated GDD accumulation over the study period in Takhini River Valley does not necessarily indicate that soils accumulated enough heat to promote germination in the spring.

Most of the energy for evaporation of soil moisture is derived from solar radiation (Rosenberg 1983). In a semi-arid environment, such as southwestern Yukon, warmer air, ground surface and soil temperatures, although favourable

Figure 4.5

Growing degree days in the air, accumulated over a 50 day period at experimental weather stations in Takhini River Valley, southern Yukon Territory (June 24-July 4, July 11-August 15, August 18-20, 1995)

Figure 4.6

Daily average ground surface temperatures recorded at corresponding north and south aspect low-, mid- and high-elevation experimental weather stations in Takhini River Valley, southern Yukon Territory (July 1-August 20, 1995)

a) Low-elevation (640 m)

b) Mid-elevation (740 m)

c) High-elevation (840 m)

sites recorded more frosts and more killing frosts ($<-2^{\circ}\text{C}$) than their corresponding south aspect sites (Table 4.6).

Oliver (1992) found that due to higher solar radiation input on south-facing slopes, soil temperatures are consistently higher than on north-facing slopes. Results from Takhini River Valley support Oliver's findings. In general, on north and south aspect slopes, soil temperatures increased until July 21, and then decreased through the end of the study period (Figure 4.7). South aspect sites recorded daily average soil temperatures between 2.3°C and 4.8°C warmer than north aspect sites at the same elevation (Table 4.5). On the south aspect slope, the low-elevation site has the highest soil temperatures, while those at the mid-elevation site are the warmest on the north aspect (Figure 4.7).

Soil temperatures are most important during sowing season and when seeds are germinating, up to three weeks after sowing (Bisset 1994). Seed germination occurred in Takhini River Valley before the beginning of the study period.

Given that by early July soil temperatures on the south aspect slope were already several degrees warmer than those on the north aspect, it is reasonable to suspect that during

Figure 4.7

Daily average soil temperatures recorded at low- (640 m), mid- (740 m) and high- (840 m) elevation north and south aspect experimental weather stations in Takhini River Valley, southern Yukon Territory (June 24-August 20, 1995)

a) North Aspect

b) South Aspect

germination south aspect slopes were more favourable than those facing north.

In Takhini River Valley, greater exposure to solar radiation on the south aspect slope allowed for more heat to accumulate in the plow layer than on the north aspect (Figure 4.8). However, the study period did not include the early growing season (May and beginning June) when soil temperatures are critical to seed germination and early plant development. Seeding time depends on the minimum soil temperature required for germination, which varies depending on crop type. For example, the minimum soil temperature for some forages, such as alfalfa, is 1°C, whereas, for pumpkins it is 16°C (Bisset 1994). Smith (1990) found that soil temperatures at a depth of 10 cm on level ground in the Whitehorse area remain below 5°C from the end of September to late May. Most seeding is complete by the end of May. Therefore, the elevated GDD accumulation over the study period in Takhini River Valley does not necessarily indicate that soils accumulated enough heat to promote germination in the spring.

Most of the energy for evaporation of soil moisture is derived from solar radiation (Rosenberg 1983). In a semi-arid environment, such as southwestern Yukon, warmer air, ground surface and soil temperatures, although favourable

Figure 4.8

Growing degree days at 15 cm in the ground, accumulated over a 50 day period at experimental weather stations in Takhini River Valley, southern Yukon Territory (June 24-July 4, July 11-August 15, August 18-20, 1995)

for crop growth and development, also contribute to low soil moisture (MacHattie and Schnelle 1974; Rosenberg 1983). In Takhini River Valley, soils (0-15 cm) at low- and mid-elevation north aspect sites have higher moisture contents than soils at corresponding south aspect sites (Figure 4.9; Table 4.7). This results largely from lower total incoming solar radiation on the north aspect slope than on the south-facing slope (Figure 4.2). Deeper soil samples (15-30 cm) could not be obtained from low- and mid-elevation south aspect sites due to soil compaction, therefore, no comparison can be drawn.

Although each of the north and south aspect high-elevation sites recorded greater soil moisture contents than the other at times during the study period, soils at these sites had essentially the same moisture content with an average difference of only 0.01% in the upper samples (S.E. 1.6; Figure 4.9; Table 4.7). This pattern was similar in the lower soil samples with an average difference in moisture content of only 0.03% (S.E. 0.8). At both high-elevation sites, the effects of solar radiation are tempered by surface roughness and soil texture. The high-elevation south aspect site was more sheltered from wind than the north-facing site, thus reducing evaporative stress on the former. When the anemometer at Site 6 was raised above tree level on

Figure 4.9

Gravimetric soil moisture content (0-15 cm) at corresponding north and south aspect low-, mid- and high-elevation experimental weather stations in Takhini River Valley, southern Yukon Territory

Table 4.7

Average difference in gravimetric soil moisture content (0-15 cm), measured at corresponding low-, mid- and high-elevation north and south aspect experimental weather stations in Takhini River Valley, southern Yukon Territory

SITES		SOIL MOISTURE CONTENT	
NORTH	SOUTH	AVG DIFF (%)	ERROR
1 (640 m)	4 (640 m)	10.5	1.6
2 (740 m)	5 (740 m)	4.5	1.8
3 (840 m)	6 (840 m)	0.01	1.6

AVG DIFF=average difference (north-south)

ERROR=standard error of the difference

bold type=difference is statistically significant ($p < 0.05$)

Figure 4.13

Relation between soil moisture content at field capacity (-0.3 bar) and wilting point (-15 bar), and gravimetric soil moisture contents at high-elevation (840 m) experimental weather stations in Takhini River Valley, southern Yukon Territory

a) North Aspect (840 m)

b) South Aspect (840 m)

Figure 4.10

Daily average wind speed recorded at north and south aspect high-elevation (840 m) experimental weather stations in Takhini River Valley, southern Yukon Territory (June 27-August 20, 1995)

Figure 4.11

Relation between soil moisture content at field capacity (-0.3 bar) and wilting point (-15 bar), and gravimetric soil moisture contents at low-elevation (640 m) experimental weather stations in Takhini River Valley, southern Yukon Territory

a) North Aspect (640 m)

b) South Aspect (640 m)

Figure 4.12

Relation between soil moisture content at field capacity (-0.3 bar) and wilting point (-15 bar), and gravimetric soil moisture contents at mid-elevation (740 m) experimental weather stations in Takhini River Valley, southern Yukon Territory

a) North Aspect (740 m)

b) South Aspect (740 m)

Table 4.9

Average difference in daily average and maximum wind speeds recorded at corresponding low-, mid- and high-elevation experimental weather stations on north and south aspect slopes in Takhini River Valley, southern Yukon Territory (June 24-August 20, 1995)

SITES		AVERAGE WIND SPEED (km/h)		MAXIMUM WIND SPEED (km/h)	
SOUTH	NORTH	AVG DIFF	ERROR	AVG DIFF	ERROR
4 (640 m)	1 (640 m)	0.4	0.3	0.9	0.7
5 (740 m)	2 (740 m)	2.1	0.3	4.9	0.6
6 (840 m)	3 (840 m)	-0.3	0.2	0.2	0.5

AVG DIFF=average difference (south-north)

ERROR=standard error of the difference

bold type=difference is statistically significant ($p < 0.05$)

than those on the north aspect, but also more restricting to crop growth, especially at Site 4.

Soil moisture must be maintained considerably above the wilting point, and preferably near field capacity, if plants are to grow and function normally (Bisset 1994). However, prolonged moisture content above field capacity may be harmful to plants (Brady 1990). The soil at Sites 2 and 3 recorded one and two moisture contents above field capacity respectively (Figures 4.12 and 4.13).

Whiteman and Allwine (1989) also found south aspect slopes to be drier than north-facing slopes because of increased incoming solar radiation. In Takhini River Valley, the higher number of plant species at the low-elevation north aspect site than the south aspect site, reflects a less harsh environment when soil moisture is considered (Table 4.8).

Wet soils are also cooled by loss of latent heat through evaporation (MacHattie and Schnelle 1974; Oke 1987). Reduced evaporation on south aspect slopes from a lack of soil moisture can result in large ground surface and soil temperature differences between slopes (MacHattie and Schnelle 1974). Evaporative cooling of moist soils at low-elevation sites in Takhini River Valley is reflected in

Table 4.8

Number of plant species at low elevation (640 m) north and south aspect vegetation sampling sites in Takhini River Valley, southern Yukon Territory

SITE ASPECT	NUMBER OF PLANT SPECIES
North	16
South	8

cooler soil temperatures at 640 m on the north aspect, than at the same elevation on the south-facing slope (Table 4.5).

In general, south aspect sites in Takhini River Valley recorded higher daily average and maximum wind speeds than north aspect sites (Table 4.9). Local site characteristics influence wind speed recorded at the research stations. South-facing sites, except the high-elevation site, were located in open fields and therefore less sheltered than the north aspect stations. Higher wind speeds also contributed to lower soil moisture values through evaporation at south-facing sites than at north aspect sites (Rosenberg 1983; Wahl et al. 1987).

In Takhini River Valley, crop production on south aspect slopes is favoured by warmer air, ground surface and soil temperatures, but is limited by soil moisture, especially at lower elevations.

4.2.2 Validity of 820 m elevation limit for cultivated agriculture

Yukon Agricultural Association (1994) and Smith (1992) state that sites above 820 m in elevation in Yukon are non-arable due to climatic limitations. This limit may be more applicable to sites on north rather than south aspect slopes. Although this guideline is enforced in the

Table 4.9

Average difference in daily average and maximum wind speeds recorded at corresponding low-, mid- and high-elevation experimental weather stations on north and south aspect slopes in Takhini River Valley, southern Yukon Territory (June 24-August 20, 1995)

SITES		AVERAGE WIND SPEED (km/h)		MAXIMUM WIND SPEED (km/h)	
SOUTH	NORTH	AVG DIFF	ERROR	AVG DIFF	ERROR
4 (640 m)	1 (640 m)	0.4	0.3	0.9	0.7
5 (740 m)	2 (740 m)	2.1	0.3	4.9	0.6
6 (840 m)	3 (840 m)	-0.3	0.2	0.2	0.5

AVG DIFF=average difference (south-north)

ERROR=standard error of the difference

bold type=difference is statistically significant ($p < 0.05$)

assessment of agricultural land development proposals by Yukon Renewable Resources, it has not been tested in the field (Smith pers. comm. June 13, 1996). In Takhini River Valley, this elevation limit restricting cultivation was assessed by a comparison of agroclimatic factors at mid- (740 m) and high- (840 m) elevation experimental weather stations.

Site 2 on the north aspect slope recorded higher daily minimum air temperatures, and significantly warmer daily average and maximum air temperatures than Site 3 on the same aspect (Table 4.10). Site 3 also recorded two frosts, whereas Site 2 did not record any (Table 4.6). On the south aspect slope, Site 5 recorded higher daily average and minimum air temperatures than Site 6, but Site 6 recorded higher daily maximum air temperatures than Site 5 (Table 4.10). Greater shelter and lower wind speed at Site 6 may have caused the higher maximum air temperatures there than at Site 5. Neither the mid- or high-elevation sites on the south aspect slopes recorded any air temperatures below 0°C (Table 4.6). The significant difference in air temperatures between 740 m and 840 m on the north aspect slope, indicates that growing conditions deteriorate more with increasing elevation on north-facing than south-facing slopes.

Table 4.10

Average difference in air, ground surface and soil temperatures between mid- and high-elevation experimental weather stations on north and south aspect slopes in Takhini River Valley, southern Yukon Territory (June 24-August 20, 1995)

AIR TEMPERATURE (°C)									
SITES		AVERAGE		MAXIMUM		MINIMUM			
A	B	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR
2 (m.n.)	3 (h.n.)	0.6	0.5	1.2	0.7	0.2	0.6		
5 (m.s.)	6 (h.s.)	0.5	0.5	-0.3	0.7	0.3	0.6		
SURFACE TEMPERATURE (°C)									
SITES		AVERAGE		MAXIMUM		MINIMUM			
A	B	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR
2 (m.n.)	3 (h.n.)	0.5	0.5	-2.3	0.9	1.2	0.8		
5 (m.s.)	6 (h.s.)	0.8	0.5	-3.3	1.0	1.0	0.7		
SOIL TEMPERATURE (°C)									
SITES		AVERAGE		MAXIMUM		MINIMUM			
A	B	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR
2 (m.n.)	3 (h.n.)	3.5	0.2	3.9	0.2	3.1	0.2		
5 (m.s.)	6 (h.s.)	2.0	0.3	2.6	0.4	1.4	0.3		

m=mid elevation (740 m)

h=high elevation (840 m)

s=south aspect

n=north aspect

Avg Diff=average difference (A-B)

Error=standard error of the difference

bold type=difference is statistically significant ($p<0.05$)

The difference in accumulation of growing degree days between mid- and high-elevation south aspect sites was minimal (Figure 4.5). The difference is larger on the north aspect with 428 growing degree days at the mid-elevation site, and only 395 at the high-elevation site (Figure 4.5). The minimal difference in GDD on the south-facing slope does not indicate any change in heat accumulation across the 820 m elevation limit.

Mid-elevation sites recorded higher daily average and minimum ground surface temperatures than high-elevation sites on the same aspect (Table 4.10). However, daily maximum surface temperatures at high-elevation sites were significantly greater than those at mid-elevation sites on the same aspect (Table 4.10). Site 3 on the north aspect slope recorded five more frosts, and 2 more killing frosts than the mid-elevation site on the same slope (Table 4.6). The high-elevation site on the south aspect only recorded one more frost than the mid-elevation site, and neither mid- or high-elevation sites on the south aspect recorded any killing frosts at the ground surface (Table 4.6). The absence of killing frosts at both the mid- and high-elevation south aspect sites, compromises the validity of the elevation limit on that aspect. More frosts are recorded

at 5 cm above the ground surface than at 1.5 m due to the nighttime inversion (Table 4.6).

Daily average, maximum and minimum soil temperatures were significantly higher at the mid-elevation sites on both north and south aspect slopes than at the high-elevation sites on the same aspect (Table 4.10). The average difference between Sites 2 and 3 on the north aspect was 3.5°C (S.E. 0.22) compared to 2.0°C (S.E. 0.33) between Sites 5 and 6 on the south aspect (Table 4.10). This suggests a more severe decrease in soil temperatures on the north-facing slope than on the south aspect slope.

The reappearance of plant species is further evidence of a more homogeneous climate across the 820 m limit on the south slope than on the north slope. Five of seven plant species present at 790 m on the south slope also occur at 840 m compared to only three on the north slope (Table 4.11). For a plant species to grow at two locations, these locations must share certain climatic conditions. The more species common to the two sites, the greater the climatic similarity between sites. For this reason, the higher reappearance rate on the south aspect supports the argument that climatic conditions are similar at both 790 m and 840 m.

Table 4.11

Comparison of the reappearance rate of plant species from
790 m to 840 m on north and south aspect slopes in Takhini
River Valley, southern Yukon Territory

Slope Aspect	Number of Species at 790 m	Number of Species Recurring at 840 m
North	7	3
South	7	5

Soil moisture decreased with increasing elevation from 740 m to 840 m on the north-facing slope, and increased from 740 m to 840 m on the south aspect slope, however, these differences were not statistically significant ($U_3=59$, $p>0.05$; $U_5=52$, $p>0.05$; Figure 4.14). The soil at both 740 m and 840 m experimental weather stations on the south-facing slope is a silt loam (see Table 3.2). At the beginning of the study period, the soil moisture content at Site 5 was below the wilting point, whereas the soil at Site 6 did not record any moisture contents below this point (Figures 4.12 and 4.13). The difference in soil type between 740 m and 840 m on the north aspect slope accounts for some of the difference in soil moisture between the two sites. The soil at 740 m is a silt loam, whereas the soil at 840 m is a sandy loam (see Table 3.2). A sandy loam soil does not retain water as well as silt loam. Poor water retention is a limiting factor to crop growth. During the study period, both these soils had moisture contents above field capacity (Figures 4.12 and 4.13). This may restrict crop growth (Brady 1990).

The presence of sandy loam at Site 3, on the north aspect, corresponds to work by Agriculture Canada (1992), which indicated that soils at higher elevations in the

Figure 4.14

Gravimetric soil moisture content at mid- (740 m) and high- (840 m) elevation north and south aspect experimental weather stations in Takhini River Valley, southern Yukon Territory

a) North Aspect

b) South Aspect

Valley are of glaciofluvial origin. Within the semi-arid environment of southwestern Yukon, coarser soils are less favoured for agriculture.

The minimal difference in growing degree day accumulations between Sites 5 and 6, and the absence of killing frosts at the ground surface at both these sites, combined with a high reappearance rate of plant species between 790 m and 840 m, compromises the validity of the 820 m elevation limit imposed on agricultural landuse on south-facing slopes in Takhini River Valley. This elevation limit may, however, be appropriate for north-facing slopes, because of a less homogeneous agroclimate across the elevation limit. This is reflected in a decrease in heat accumulation both in the air and in the soil, an increased number of killing frosts at the ground surface, and a reduced reappearance rate of plant species.

4.2.3 Agroclimate of low-elevation sites

Previous climatological and crop trial research in Yukon suggested that low-elevation sites near the Takhini River, approximately 640 m, are best for cultivated agriculture (Eley and Findlay 1977; Bisset 1990). However, Bisset's (1990) three crop trial sites in the Whitehorse area were all at approximately 640 m elevation, and

vegetable trials were treated with improvement practices such as irrigation, rhizobium inoculation and plastic mulch. The research did not investigate higher elevation sites in the Valley, and potentially compensated for low minimum temperatures through improvement practices.

Current research in Takhini River Valley does not support Eley and Findlay's (1977) or Bisset's (1996) conclusions, on the basis of measured temperatures and soil characteristics at low- and mid-elevation sites. However, due to aridity in southern Yukon, farmers prefer agricultural sites near rivers or lakes for irrigation purposes.

In general, frost occurrences in Takhini River Valley decreased with increasing elevation, from 640 m to 740 m (Table 4.6). Minimum air temperatures below 0°C can be detrimental to crop growth, especially at the beginning of the growing season when plants are small and more susceptible to freezing. Even if daily temperatures reach high maxima, night frosts can kill plants (Chang 1968; Rosenberg et al. 1983).

Low-elevation sites on north and south aspect slopes recorded more frosts and lower minimum air temperatures than mid-elevation sites on their respective slopes (Tables 4.6 and 4.12; Figure 4.15). The low-elevation north aspect site

Table 4.12

Average difference in air, ground surface and soil temperatures between low- and mid-elevation experimental weather stations on north and south aspect slopes in Takhini River Valley, southern Yukon (June 24-August 20, 1995)

AIR TEMPERATURE (°C)									
SITES		AVERAGE		MAXIMUM		MINIMUM			
A	B	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR
2 (m.n.)	1 (l.n.)	0.3	0.5	0.4	0.7	1.4	0.7		
5 (m.s.)	4 (l.s.)	0.1	0.5	-1.1	0.6	2.0	0.7		
SURFACE TEMPERATURE (°C)									
SITES		AVERAGE		MAXIMUM		MINIMUM			
A	B	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR
2 (m.n.)	1 (l.n.)	-0.4	0.5	-3.9	0.8	1.7	0.8		
5 (m.s.)	4 (l.s.)	-0.6	0.6	-5.9	1.1	1.6	0.8		
SOIL TEMPERATURE (°C)									
SITES		AVERAGE		MAXIMUM		MINIMUM			
A	B	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR
2 (m.n.)	1 (l.n.)	1.5	0.3	1.9	0.3	1.1	0.3		
5 (m.s.)	4 (l.s.)	-1.1	0.4	-0.5	0.4	1.7	0.3		

l=low elevation (640 m)

m=mid elevation (740 m)

s=south aspect

n=north aspect

Avg Diff=average difference (A-B)

Error=standard error of the difference

bold type=difference is statistically significant ($p < 0.05$)

Figure 4.15

Daily minimum air temperatures recorded at low- (640 m) and mid- (740 m) elevation north and south aspect experimental weather stations in Takhini River Valley, southern Yukon Territory (June 25-August 20, 1995)

a) North Aspect

b) South Aspect

recorded seven frosts, and the south-facing site recorded four (Table 4.6). Mid-elevation sites on north and south-facing slopes did not record any frosts (Table 4.6). These latter sites may be located within the thermal belt, above the night inversion in the valley. The ceiling of the night inversion is located somewhere between 640 m and 740 m. On the south aspect slope, the thermal belt may extend above 840 m. On the north aspect, the occurrence of frosts at 840 m may indicate that the thermal belt ends at or below this elevation (Table 4.6). These findings support previous results from other research. MacHattie (1970) found the lowest minimum air temperatures in valley bottoms due to the night-time inversion. Eley and Findlay (1977) concluded that frost hazard, due to cold-air drainage and pooling, decreases with increasing elevation, even though the average air temperature also decreases with altitude.

In Takhini River Valley, low minimum air temperatures developed from cold-air draining and pooling into the valley bottom and radiative longwave cooling at the ground surface. Cold-air drainage was more evident on the north-facing slope than on the south aspect slope, contributing to more frequent frosts at the low elevation site, on the former (Figure 4.16). The mid-elevation south-facing site was a gentle crescent shaped slope of 4.5° , which may not have

Anabatic and katabatic slope winds recorded on July 7 and 8 1995, under sunny conditions, at north and south aspect mid-elevation (740 m) experimental weather stations in Takhini River Valley, southern Yukon Territory

a) North Aspect

b) South Aspect

recorded upslope and downslope winds that a steeper site, such as Site 2 at 14.5° inclination would have. As Eley and Findlay (1977) found, steeper slopes like the one at Site 2 have better cold-air drainage than shallow slopes.

Oke (1987) found that slope winds are best developed in the summer under cloudless skies with weak large-scale air motion. However, MacHattie (1968) found local wind patterns may be more obvious on cloudier days. On days with increased solar radiation, convective activity, as well as the coupling of surface and synoptic winds tend to be more pronounced, overshadowing local wind patterns (MacHattie 1968). In Takhini River Valley, anabatic and katabatic winds were not evident on the south-facing slope on either sample sunny or cloudy days for reasons previously discussed (Figures 4.16 and 4.17). On the north aspect, slope winds were more evident on sample sunny days, and obvious, but less well developed, on sample cloudy days (Figures 4.16 and 4.17).

Low minimum air temperatures previously discussed, are reflected in lower heat accumulation at low-elevation sites in Takhini River Valley. Sites 1 and 4 accumulated fewer growing degree days than mid-elevation sites by as much as 45 units on the same aspect (Figure 4.5).

Anabatic and katabatic slope winds recorded on July 21 and 22 1995, under cloudy conditions at north and south aspect mid-elevation (740 m) experimental weather stations in Takhini River Valley, southern Yukon Territory

a) North Aspect

b) South Aspect

Shaw (1954) demonstrated that minimum temperatures measured in standard weather shelters provided little information on the temperature of leaves during a frost event, therefore, temperatures recorded near the ground surface are beneficial to crop monitoring. Ground surface temperatures are also important for crop growth, especially in the spring when plants are small and killing frosts more likely. The two low-elevation sites recorded the most frosts at 5 cm above the ground surface in Takhini River Valley (Table 4.6). Site 1 on the north aspect recorded 14 frosts, 10 of which were killing frosts ($<-2^{\circ}\text{C}$), and Site 4 on the south aspect recorded 11 frosts, four of which were killing frosts (Table 4.6). There were no killing frosts, at 5 cm above the ground surface, at mid-elevation sites on either the north or south aspect slopes (Table 4.6). The absence of killing frosts at mid-elevation sites suggests that these sites are situated within the Valley's thermal belt.

In Takhini River Valley, the mid-elevation north aspect site and the low-elevation south aspect site recorded higher soil temperatures and greater GDD at 15 cm in the ground than other sites on their respective aspects (Table 4.12; Figure 4.8). On the north aspect, higher soil moisture and ground surface temperatures at Site 1 resulted in a smaller

increase in soil temperature, than at the mid-elevation site, due to increased evaporation (Table 4.13). Soil GDD were greatest at the low-elevation south aspect site (Figure 4.8). The 573 GDD in the plow layer at this site are greater than the GDD accumulated 1.5 m above the ground.

Reiners et al. (1984) found soil moisture to increase with altitude in the White Mountains of New Hampshire. At Takhini River Valley experimental weather stations, soil moisture content decreased from 640 m to 740 m on the north aspect slope (Figure 4.18; Table 4.13). The soil at Site 1, retained more water due to its higher percentage of clay (24%), compared to only 6% clay at Site 2 (see Table 3.2). Soil moisture contents at Site 1 were closer to the wilting point throughout the study period than those at Site 2 (Figures 4.11 and 4.12). Optimum plant growth occurs when the soil moisture content is near field capacity (Brady 1990). The increase in soil moisture content from 640 m to 740 m on the south aspect slope was not statistically significant ($U_4=57$, $p>0.05$; Figure 4.18; Table 4.13).

In general, precipitation increases with elevation (Wahl et al. 1987). The amount of precipitation collected in rain gauges at Takhini River Valley experimental stations was very sporadic with no clear pattern with elevation (Figure 4.19). Although this may reflect the actual pattern

Table 4.13

Average difference in gravimetric soil moisture content
(0-15 cm) at low- (640 m) and mid- (740 m) elevation north
and south aspect experimental weather stations in Takhini
River Valley, southern Yukon Territory

SITES		SOIL MOISTURE CONTENT (%)	
A	B	AVG DIFF	ERROR
1 (l.n.)	2 (m.n.)	4.3	1.8
4 (l.s.)	5 (m.s.)	-1.8	1.6

l=low-elevation (640 m)

m=mid-elevation (740 m)

n=north aspect

s=south aspect

AVG DIFF=average difference (A-B)

ERROR=standard error of the difference

bold type=difference is statistically significant ($p < 0.05$)

Figure 4.18

Gravimetric soil moisture content at low- (640 m) and mid- (740 m) elevation north and south aspect experimental weather stations in Takhini River Valley, southern Yukon Territory

a) North Aspect

b) South Aspect

Figure 4.19

Precipitation (mm) recorded at experimental weather stations
in Takhini River Valley, southern Yukon Territory

daily maxima are high, but only for a short period of time each day.

For the two methods of calculating means, GDD accumulations would be different on a daily and monthly basis. This implies that GDD calculated by the Atmospheric Environment Service underestimate the heat accumulation for the growing season, especially at low-elevation sites where frosts are more common. Growing degree days calculated from many temperature observations throughout a day better reflect heat accumulation than GDD calculated from a mean temperature based on maximum and minimum observations.

The GDD concept is more appropriate for southern rather than northern agriculture. The GDD concept is also compromised by mountainous terrain where air temperatures, especially minimum air temperatures, are dependent on local topography. Long summer daylight hours in northern regions also reduce the reliability of GDD as an indicator of agricultural potential, however the use of effective growing degree days alleviates this limitation.

4.2.5 Regional representativeness of the Whitehorse Airport weather data

The Atmospheric Environment Service weather station at Whitehorse Airport is the principal weather station for the

temperature with advancing stages of crop development. During spring, the soil warms up more slowly than the air. If degree days are accumulated on the basis of air temperature, the totals may be inappropriately high for agricultural applications. In spring, soil temperatures may be used to calculate growing degree days until plant emergence (Edey 1977).

The growing degree day concept assumes that the variation in daily temperature is sinusoidal. Although air temperature observations at experimental weather stations approached this sinusoidal pattern on some days, such as July 7 and 8, this pattern was not consistent, as evident on July 21 and 22 (Figures 4.20 and 4.21). Variations in total GDD occurred with different calculation methods (Figure 4.22). Therefore, the GDD index is sensitive to methods used to derive daily mean temperatures.

The two methods to determine GDD accumulations at experimental stations, in section 4.1, provided different results (Figure 4.22). In general, the average of the daily maximum and minimum air temperature gave a lower GDD accumulation than the mean of more temperature observations throughout the day, with the exception of Site 6 (Figure 4.22). This could be caused by a temperature pattern where

Figure 4.20

Sinusoidal pattern exhibited by air temperatures recorded on
July 7 and 8 1995, in Takhini River Valley,
southern Yukon Territory

Figure 4.21

Non-sinusoidal pattern exhibited by air temperatures recorded on July 21 and 22 1995, in Takhini River Valley, southern Yukon Territory

Figure 4.22

Growing degree days determined for two methods of calculating daily mean air temperatures at experimental weather stations in Takhini River Valley, southern Yukon Territory

daily maxima are high, but only for a short period of time each day.

For the two methods of calculating means, GDD accumulations would be different on a daily and monthly basis. This implies that GDD calculated by the Atmospheric Environment Service underestimate the heat accumulation for the growing season, especially at low-elevation sites where frosts are more common. Growing degree days calculated from many temperature observations throughout a day better reflect heat accumulation than GDD calculated from a mean temperature based on maximum and minimum observations.

The GDD concept is more appropriate for southern rather than northern agriculture. The GDD concept is also compromised by mountainous terrain where air temperatures, especially minimum air temperatures, are dependent on local topography. Long summer daylight hours in northern regions also reduce the reliability of GDD as an indicator of agricultural potential, however the use of effective growing degree days alleviates this limitation.

4.2.5 Regional representativeness of the Whitehorse Airport weather data

The Atmospheric Environment Service weather station at Whitehorse Airport is the principal weather station for the

area, including Takhini River Valley. It is important to determine if weather conditions reported at the Airport are representative of agricultural areas within the Valley, because farmers consider these reports when regulating their agricultural activities. The representativeness of weather observations collected at Whitehorse Airport of conditions in Takhini River Valley is assessed by a comparison between Airport, experimental and permanent Valley weather stations.

The Whitehorse Airport recorded significantly higher daily minimum air temperatures than all experimental weather stations on the north aspect slope, as well as the low-elevation south aspect site, the Forestry station and Takhini River Ranch (Tables 4.14 and 4.15). The Airport Weather Station did not record any of the frosts detected at experimental or permanent weather stations in Takhini River Valley (Table 4.6). The Forestry station recorded many of the same frosts as the low-elevation north aspect experimental station (Site 1; Figure 4.23). This station could be used to help predict frost occurrences in the Valley. Whitehorse Airport does not predict frosts which threaten crops, especially at low-elevations and north aspect sites in Takhini River Valley.

Growing degree days calculated for the Airport were greater than those accumulated at the north aspect sites,

Table 4.14

Average difference in air temperature observations between experimental weather stations in Takhini River Valley and Whitehorse Airport, southern Yukon Territory (June 24-August 20, 1995)

AIR TEMPERATURE (°C)		SITES					
A	B	AVERAGE		MAXIMUM		MINIMUM	
		AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR
W.A.	1 (l.n.)	1.2	0.5	-0.7	0.6	3.0	0.7
W.A.	2 (m.n.)	0.3	0.5	-1.0	0.7	1.6	0.6
W.A.	3 (h.n.)	1.0	0.5	0.2	0.6	1.8	0.6
W.A.	4 (l.s.)	0.5	0.5	-1.1	0.6	2.0	0.7
W.A.	5 (m.s.)	0.1	0.5	0.02	0.6	0.2	0.6
W.A.	6 (h.s.)	0.1	0.5	-0.3	0.6	0.4	0.5

W.A.=Whitehorse Airport (703 m)

l=low elevation (640 m)

m=mid elevation (740 m)

h=high elevation (840 m)

s=south aspect

n=north aspect

Avg Diff=average difference (A-B)

Error=standard error of the difference

bold type=difference is statistically significant ($p<0.05$)

Table 4.15

Average difference in air temperature observations between Whitehorse Airport and permanent weather stations in Takhini River Valley, southern Yukon Territory (June 24-August 20, 1995)

SITES		AVERAGE		MAXIMUM		MINIMUM	
A	B	AVG DIFF	ERROR	AVG DIFF	ERROR	AVG DIFF	ERROR
Airport	Mayo Road	-1.0	0.5	-2.5	0.6	0.5	0.7
Airport	Forestry	0.7	0.5	-0.5	0.6	1.8	0.7
Airport	Hackney Farm	0.4	0.6	-0.1	0.6	0.9	0.6
Airport	Porter Creek	0.1	0.5	-0.03	0.6	0.3	0.6
Airport	Takhini Ranch	0.7	0.6	-0.3	0.6	2.1	0.6

Avg Diff=average difference (A-B)

Error=standard error of the difference

bold type=difference is statistically significant ($p<0.05$)

Station Elevation

Whitehorse Airport 703 m

Mayo Road 655 m

Forestry 670 m

Porter Creek 713 m

Takhini Ranch 756 m

Hackney Farm 686 m

Figure 4.23

Daily minimum air temperatures recorded at the north aspect low-elevation (640 m) experimental weather station and the Forestry (670 m) weather station in Takhini River Valley, southern Yukon Territory (June 25-August 20, 1995)

the low-elevation south aspect site, and all permanent weather stations except Mayo Road (Figure 4.24). Growing degree days at the Airport corresponded closely to those accumulated at Sites 5 and 6 in the Valley, while GDD at Mayo Road station were the greatest (Figure 4.24). Although Mayo Road station is not in Takhini River Valley, data from this station were used due to its proximity to all other weather stations in the study area. With respect to heat accumulation, observations at the Airport station are similar to some of the more favourable agricultural sites within the Valley.

Differences in observations between weather stations depend not only on distance and topoclimatic factors, but also on differences in monitoring equipment.

The Airport weather station is on a bench above the Yukon River at an elevation of 703 m, approximately 15 kilometers from the confluence of Yukon and Takhini Rivers. The weather station at the Airport is a standard AES site, therefore air temperatures are measured over a level grassy surface, without influence of slope or aspect, reducing the effects of cold-air drainage and pooling. Therefore minimum air temperatures recorded at the Airport are higher than those recorded at some low-elevation sites in the Valley (Tables 4.14 and 4.15). Because Sites 2 and 3

Figure 4.24

Growing degree days accumulated for a 50 day period at experimental and permanent weather stations in Takhini River Valley, southern Yukon Territory (June 24-July 4, July 11-August 15, August 18-20, 1995)

Station	Elevation (a.s.l.)
1 (north)	640 m
2 (north)	740 m
3 (north)	840 m
4 (south)	640 m
5 (south)	740 m
6 (south)	840 m
Whitehorse Airport	703 m
Mayo Road	655 m
Hackney Farm	686 m
Takhini Ranch	756 m
Porter Creek	713 m
Forestry	670 m

are both higher in elevation than the Airport and are facing north, they recorded lower air temperatures. The Airport is not representative of all agricultural land within the Valley because the former is not influenced by slope or aspect, and most agricultural land in the Valley is rolling and at lower elevations.

Regardless of differences in daily average temperature observations, all experimental and permanent weather stations showed similar monthly patterns in average, maximum and minimum air temperatures (Figure 4.1). The day to day variability in average and maximum air temperature, and to a lesser degree minimum air temperatures, decreased towards the end of July and remained steady in August (Figure 4.1). This similarity is demonstrated by comparable standard deviations of daily average temperatures around the monthly mean (Table 4.16). In this way, Whitehorse Airport is representative of the cyclical pattern of daily temperatures found in Takhini River Valley.

The similarity in air temperature patterns is further demonstrated by statistically significant correlation coefficients between all sites for the entire season, as well as from June 24 to July 23, and July 24 to August 20 ($p > 0.05$; Table 4.17). The pattern of minimum air temperatures recorded at Whitehorse Airport also correlates

Table 4.16

Standard deviations around the monthly mean for the
 Whitehorse Airport, experimental and permanent weather
 stations in Takhini River Valley,
 southern Yukon Territory

STANDARD DEVIATION

SITES	June 25-July 22	July 23-August 20
Whitehorse A. (703m)	2.4	1.4
Site 1 (N 640m)	2.7	1.8
Site 2 (N 740m)	2.7	1.7
Site 3 (N 840m)	2.8	1.5
Site 4 (S 640m)	2.9	1.7
Site 5 (S 740m)	2.7	1.5
Site 6 (S 840m)	2.6	1.6
Mayo Road (655m)	2.5	1.7
Forestry (670m)	2.7	1.8
Hackney Farm (686m)	2.6	1.6
Porter Creek (713m)	2.5	1.3
Takhini Ranch (756m)	2.7	1.4

Table 4.17

Correlation coefficients (r_s) for average and minimum air temperatures recorded at Whitehorse Airport (W.A.), experimental and permanent weather stations in Takhini River Valley, southern Yukon Territory

AVERAGE AIR TEMPERATURE			
Weather Stations	Jun 24-Aug 20	Jun 24-Jul 23	Jul 24-Aug 20
W.A. and Site 1	0.85	0.85	0.61
W.A. and Site 2	0.92	0.96	0.69
W.A. and Site 3	0.92	0.92	0.78
W.A. and Site 4	0.86	0.87	0.63
W.A. and Site 5	0.87	0.84	0.72
W.A. and Site 6	0.87	0.89	0.64
W.A. and Mayo Road	0.89	0.87	0.74
W.A. and Hackney Farm	0.85	0.85	0.56
W.A. and Takhini Ranch	0.63	0.50	0.33
W.A. and Porter Creek	0.93	0.92	0.81
W.A. and Forestry	0.88	0.85	0.76
MINIMUM AIR TEMPERATURE			
W.A. and Site 1	0.74	0.73	0.69
W.A. and Site 2	0.89	0.92	0.81
W.A. and Site 3	0.82	0.83	0.72
W.A. and Site 4	0.77	0.74	0.69
W.A. and Site 5	0.75	0.60	0.81
W.A. and Site 6	0.79	0.77	0.73
W.A. and Mayo Road	0.81	0.75	0.80
W.A. and Hackney Farm	0.78	0.77	0.65
W.A. and Takhini Ranch	0.70	0.69	0.55
W.A. and Porter Creek	0.91	0.93	0.84
W.A. and Forestry	0.80	0.72	0.84

all correlations are statistically significant ($p < 0.05$)

with all experimental and permanent weather stations in Takhini River Valley (Table 4.17). Although correlation coefficients decreased in the second half of the season, they remained statistically significant ($p > 0.05$; Table 4.17). Synoptic weather conditions in the latter half of the summer were less stable, adding to inter-site variability.

At the Whitehorse Airport, electronic temperature sensors and maximum and minimum thermometers are housed in ventilated Stevenson screens. Permanent weather stations in the Valley record temperature extremes with maximum and minimum thermometers housed in non-ventilated Stevenson screens. All permanent stations are located on level ground without influence from slope or aspect. At experimental stations, thermistors were housed in unaspirated plastic stacked plate radiation shields, on north and south aspect slopes with varying inclinations.

The large volume of air present in Stevenson screens requires time to equilibrate to ambient air temperatures, therefore, on calm days, temperature observations are influenced by stagnant air in non-ventilated Stevenson screens (Sparks 1972; Henshall and Snelgar 1989). The temperature error for non-aspirated screens depends on wind speed (Henshall and Snelgar 1989; McIlveen 1992). McIlveen (1992) found that on calm, sunny days, the temperature

inside a Stevenson screen may be more than 1°C above the external air temperature. Since a wind as light as 7.2 km/h will ventilate a space as large as a Stevenson screen, it is unlikely that air would stagnate within the small shields at experimental stations (Matejka 1990).

The significantly higher daily maximum air temperatures recorded at Mayo Road than those observed at the Airport may result from stagnant air in the Stevenson screen, but there is no wind data for the Mayo Road Station.

Whitehorse Airport weather station is least representative of minimum air temperatures recorded in Takhini River Valley. Heat accumulation over the study period at the Airport was similar to heat accumulated at the mid- and high-elevation south aspect sites. As well, the Airport recorded similar monthly air temperature patterns to all stations within Takhini River Valley.

4.3 Summary of chapter

Data were analyzed using summary statistics, U tests and correlation analysis to assess agricultural limits imposed by elevation and aspect, and for comparison with Whitehorse Airport and five other permanent weather stations in the vicinity.

Results indicated that south-facing slopes are warmer and drier than north aspect slopes, and low-elevation sites on both aspects recorded the lowest minimum air and surface temperatures. The climatic gradient is less severe on the south aspect slope across the 820 m elevation limit than on the north-facing slope. Weather data collected at the Whitehorse Airport is most representative of mid- and high-elevation south-facing sites.

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 Summary

5.1.1 Purpose and background

The purpose of this thesis is to improve understanding of topoclimate in Takhini River Valley, southern Yukon, with respect to agricultural growing conditions. Previous agroclimatic research in southern Yukon has indicated that the best climates for agricultural production are found at low-elevations on south-facing slopes, and that sites above 820 m in elevation are non-arable.

One of the most common agroclimatic parameters determined is growing degree days. Two methods of calculating growing degree days were presented and compared using data from Takhini River Valley experimental weather stations. Although Whitehorse Airport is only a short distance from Takhini River Valley, the topography of the region puts into question the utility of weather data collected at the Airport for agricultural applications in the Valley.

This thesis examined the agroclimate of Takhini River Valley, the growing degree day concept and the

representativeness of Whitehorse Airport by assessing the variability of climate and soil parameters at six experimental weather stations of varying aspect and elevation. Weather data from five permanent stations in the area, as well as data from Whitehorse Airport, were added to the analysis.

5.1.2 Field work

Field work was carried out in June, July and August 1995. Six experimental weather stations were installed in Takhini River Valley to monitor agricultural growing conditions, three on north-facing and three on south-facing slopes. At experimental sites, aspect, measured in absolute degrees, was 0° or 180° , $\pm 15^{\circ}$, and slope was less than 15° . Sites were located at intervals of 100 m in elevation, beginning near the Takhini River at 640 m.

Variables monitored were air, surface and soil temperatures, incoming solar radiation, wind speed and direction, and precipitation. Soil samples were collected for moisture content, potential-water content, bulk density and particle size analysis. Vegetation surveys were undertaken to determine relations between elevation and vegetation patterns.

5.2 Results

There were several differences in agroclimatic parameters such as temperature, wind speed and soil moisture between stations studied. The following sections elaborate these differences.

5.2.1 Agroclimate of north and south-facing slopes

In Takhini River Valley, crop production on south aspect slopes is favoured by warmer air, ground surface and soil temperatures, and greater growing degree day accumulations, but is limited by soil moisture, especially at lower elevations.

5.2.2 Validity of 820 m elevation limit for cultivated agriculture

The minimal difference in heat accumulation, no frost occurrences, and the increase in soil moisture between mid- and high-elevation south aspect sites compromises the 820 m elevation limit for cultivated agriculture on south-facing slopes.

This limit may apply to north aspect sites because of the decrease in growing degree days and increased number of air and ground surface frosts during the growing season at 840 m.

These results are supported by a more consistent plant community between 790 m and 840 m in elevation on the south aspect slope than the north-facing slope.

5.2.3 Agroclimate of low-elevation sites

Cultivation is hindered at low-elevation sites in Takhini River Valley by low minimum air and ground surface temperatures resulting from cold-air drainage into the Valley bottom. Over the study period, the greatest number of frosts occurred at the low-elevation sites, and, due to these minima, the north aspect low-elevation site recorded the fewest growing degree days.

5.2.4 The calculation of growing degree days

The growing degree day index is sensitive to methods used to derive daily mean temperatures. In general, the average of the daily maximum and minimum air temperature gave lower GDD accumulations than the mean of more frequent temperature observations. Air temperatures recorded in Takhini River Valley generally did not display to sinusoidal pattern presupposed by the maximum/minimum method of calculating growing degree days.

5.2.5 Regional representativeness of Whitehorse Airport weather data

Standard weather stations record data at sites with minimal influence of slope and aspect, whereas most agricultural land in Takhini River Valley is undulating. The Whitehorse Airport weather station poorly represents minimum air temperatures recorded in Takhini River Valley. Growing degree days accumulated at the Airport were similar in quantity to those at the mid- and high-elevation south aspect sites, and greater than those recorded at all other experimental and permanent weather stations, except the Mayo Road station. The Airport recorded similar patterns of monthly air temperature to all experimental and permanent weather stations in Takhini River Valley.

5.3 Conclusions

- (1) Although the south aspect is drier than the north and requires more irrigation, results indicate that mid- and high-elevation, south aspect sites are most favourable for agricultural production when considering heat accumulation. On the north aspect, the most favourable site was at mid-elevation.
- (2) There is evidence of a thermal belt in the Valley which extends from between 640 m and 740 m to above 840 m on

the south aspect, and to below 840 m on the north aspect. Because of this, north and south aspect slopes should not have the same elevation limit restricting cultivated agriculture.

- (3) Evidence of cold-air drainage into the Valley bottom and multiple frosts limits agricultural production potential at low-elevation sites.

The reliability of weather data increases with the length of the sampling period. Therefore, the data collected over the short time of this survey may be restricted in its applicability.

Although agroclimatic parameters such as growing degree day accumulations, frost occurrences and soil moisture are important for determining preferred agricultural locations, the best sites for agriculture cannot be determined from agroclimatic parameters alone. The distribution of cultivated land in Yukon depends largely on land availability and accessibility, proximity to communities, infrastructure, goods and services, and the availability of water for irrigation.

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